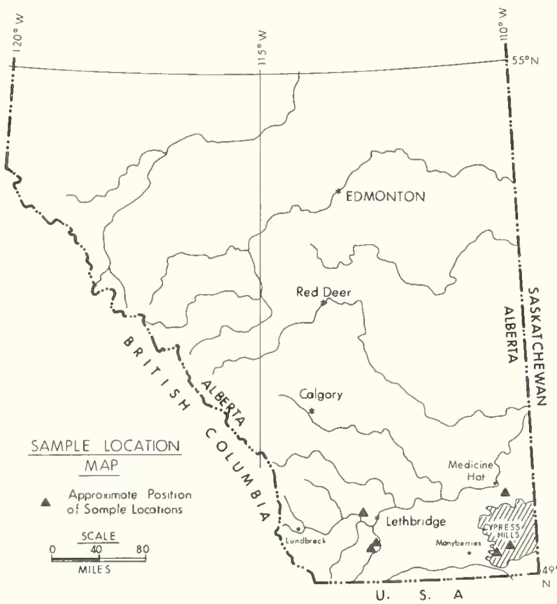
DINOFLAGELLATE CYSTS AND ACRITARCHS FROM THE BEARPAW FORMATION (UPPER CAMPANIAN) OF SOUTHERN ALBERTA, CANADA

by REX HARLAND

ABSTRACT. Fifty-three species of dinoflagellate cysts and six species of acritarchs are reported from the upper Campanian Bearpaw Formation of southern Alberta. These include *Diconodinium firmum* sp. nov., *Lejeunia parva* sp. nov., *L. ampla* sp. nov., *Spinidinium clavum* sp. nov. and *Hystrichosphaeridium dowlingii* sp. nov. The Bearpaw Formation is divided into three informal assemblage zones. A parameter called the gonyaulacacean ratio is used as a possible guide to the salinity of the Bearpaw sea or to the proximity of the coastline. Three periods of open marine conditions are postulated. These open marine conditions are intimately connected with the assemblage zones erected for the formation. Comparisons are made with Campanian assemblages of other areas.

THE Campanian Bearpaw Formation is unique in being firmly placed in the geological time-scale by virtue of its ammonite faunas and its radiometric dating. Since there is a lack of knowledge of Campanian organic-walled microplankton, the Bearpaw was an ideal body of rock on which to study these microfossils. Such a reliably dated assemblage should be valuable in any further work on Campanian or suspected Campanian strata from other areas. The Bearpaw Formation is best known from southern Alberta, so this area was chosen for the study.

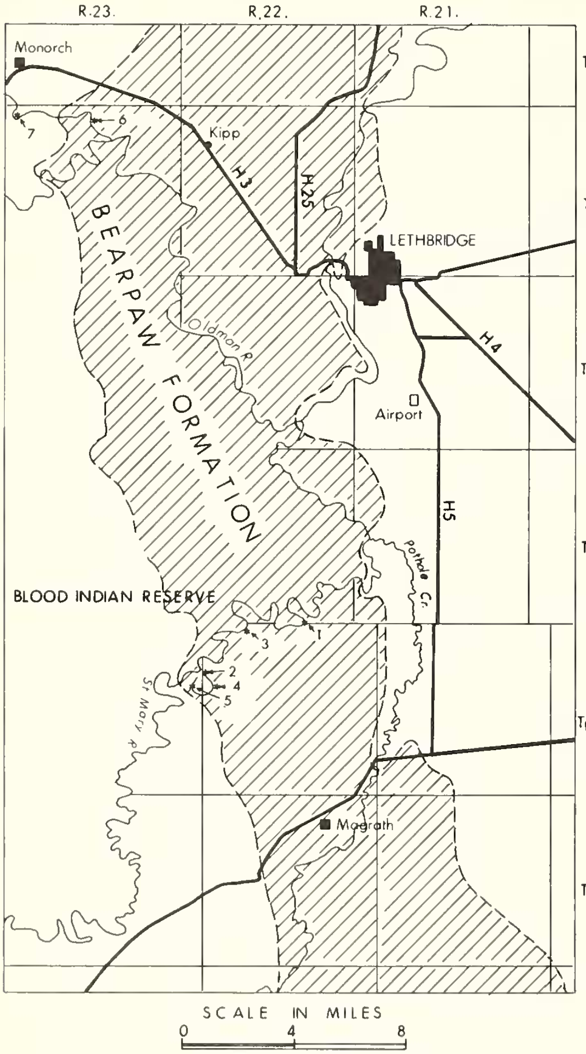


TEXT-FIG. 1. Sketch map of southern Alberta showing the approximate positions of the sample localities and the extent of the Cypress Hills (above 2500′).

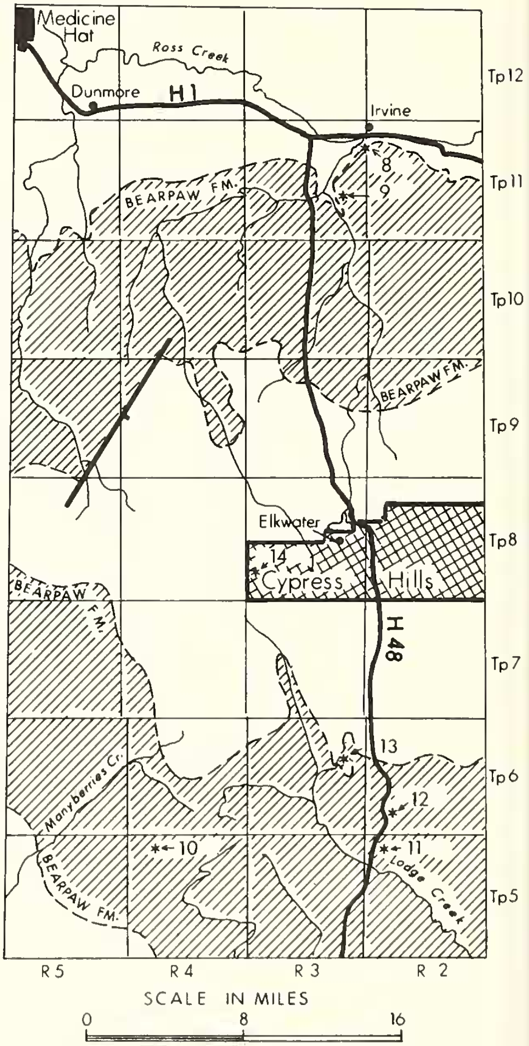
[Palaeontology, Vol. 16, Part 4, 1973, pp. 665–706, pls. 84–88.]

STRATIGRAPHY OF THE BEARPAW FORMATION

The Bearpaw Formation was named by J. B. Hatcher and T. W. Stanton (1903) from localities in the vicinity of the Bearpaw Mountains, north-central Montana. The first biostratigraphic zonation was that of Russell and Landes (1940), and Loranger and Gleddie (1953) were the first to attempt a micropalaeontological zonation. Potassium-argon radiometric dates are available for the Bearpaw Formation



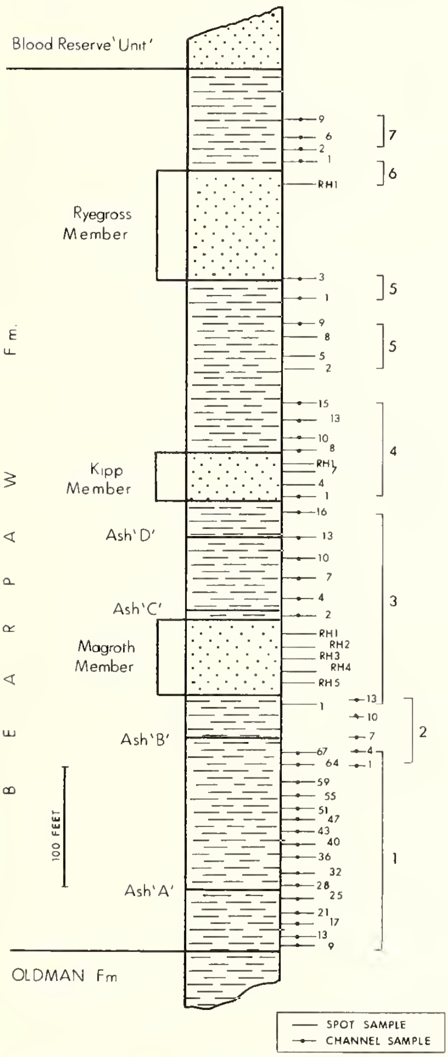
TEXT-FIG. 2. Detailed map of the Lethbridge area with the approximate outcrop pattern of the Bearpaw Formation and the positions of the sample localities. (Geology after GSC Calgary Sheet, 1928.)



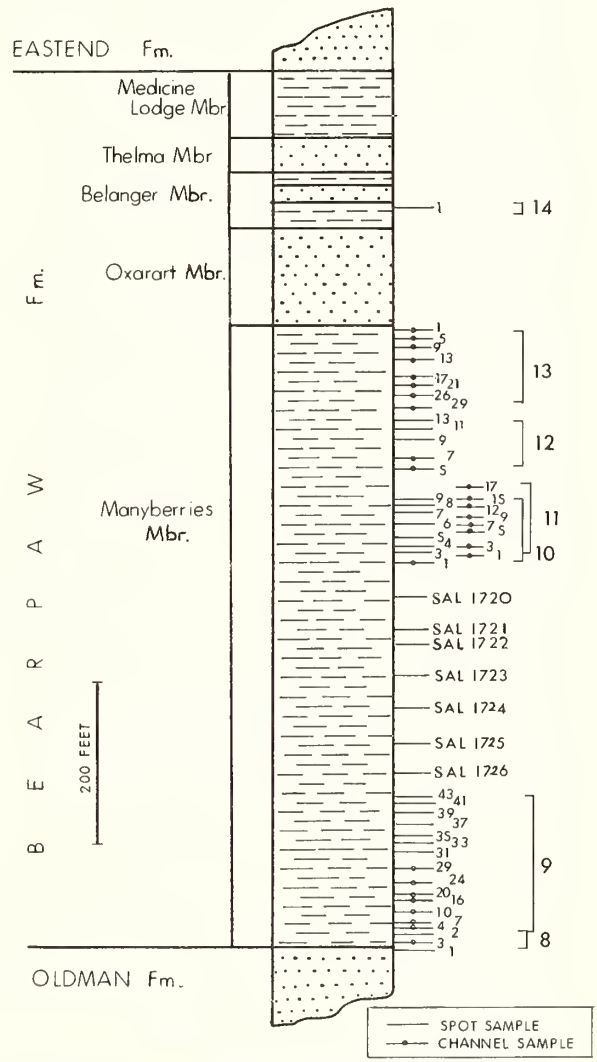
TEXT-FIG. 3. Detailed map of the Cypress Hills area with the approximate outcrop pattern of the Bearpaw Formation and the positions of the sample localities. (Geology after GSC Calgary Sheet, 1928.) The cross-hatched area indicates the Cypress Hills Provincial Park.

at 75±4 million years from a thin bentonite 65 feet above the base of the formation at Lethbridge (Folinsbee *et al.* 1960, 1961).

The Bearpaw Formation is for the most part a sub-horizontal unit except where it has been affected by the Sweetgrass Arch uplift. A maximum thickness of 1170 feet has been recorded in the Cypress Hills (Lines 1947, *in litt.* 1963), but at Lethbridge it is only 726 feet thick (Link and Childerhose 1931). The lithology of the formation is predominantly one of shales with intercalated sandstones, minor bentonites, carbonate bands, and ironstone nodule horizons. Detailed lithological descriptions



TEXT-FIG. 4. Composite stratigraphical section for the Bearpaw Formation of the Lethbridge area showing sample distribution and coding. (After Link and Childerhose 1931.)



TEXT-FIG. 5. Composite stratigraphical section for the Bearpaw Formation of the Cypress Hills area showing sample distribution and coding. (After Lines 1963.)

are given by Williams and Dyer (1930); Link and Childerhose (1931); Russell and Landes (1940); Furnival (1950); and Caldwell (1968). The base of the formation in southern Alberta is generally regarded as being isochronous (Lines 1947, *in litt.* 1963) but it becomes diachronous to the east (Caldwell 1968). The upper boundary is markedly diachronous (Russell 1950).

The age of the formation in southern Alberta is upper Campanian, for the most part lying within the zones of *Baculites compressus* sensu stricto, *B. cuneatus*, *B. reesidei*, *B. jenseni* and *B. eliasi* (Caldwell 1968). The fauna consists mainly of molluscs and foraminiferans, but full descriptions are given in Warren (in Fraser *et al.* 1935); Dowling (1917); Williams and Dyer (1930); Russell and Landes (1940); Warren (1931, 1934, 1937); Douglas (1942); and Caldwell (1968).

The deposition of the Bearpaw Formation was accomplished during the last major marine transgression in western Canadian geological history (Warren and Stelck 1958). A connection with the Arctic is indicated by the work of Martin (1960) in addition to a link with the Gulf of Mexico (Reeside 1957).

Bearpaw Formation of southern Alberta. The Bearpaw Formation of the Lethbridge area has been described by Link and Childerhose (1931) and is exposed in the valley of the St. Mary River (fig. 2), especially in the cut bank sides of meanders. The regional dip of the formation is less than 10 degrees in a westerly direction. Locally, however, there are normal faults and open folds. The Cypress Hills, a plateau remnant, is capped by the Cypress Hills Formation of Oligocene age and is ringed by successively older strata including the Bearpaw Formation. The latter is essentially flat-lying and no complete section of the formation is exposed here. Lines (1947, *in litt.*, 1963) gives the most complete description (see fig. 5). The regional dip is less than 10 degrees in an easterly direction, little faulting has occurred, but there is much slumping and deep weathering.

Treatment. The distribution and type of sampling of the two sections is illustrated in figs. 4 and 5. The samples are stored at the Research Council of Alberta, at Edmonton. A standard palynological preparation technique was used but beyond the hydrofluoric acid stage all the samples were handled using the filtration system of Neves and Dale (1963). A Leitz Laborlux microscope 595949 was used with the slide label to the right of the observer. A reference co-ordinate for the upper left corner of the slide is given on the slide labels, following Pierce (1959). A set of slides is in the Department of Geology, University of Alberta. Specimens were photographed under Leitz Ortholux microscope 594209, equipped with an Orthomat camera attachment. Adox KB 14 film was used. All holotypes and figured specimens are in the Palynological Collections of the Research Council of Alberta at Edmonton.

SYSTEMATIC DESCRIPTIONS

The abbreviations O.D. and S.D. are used to indicate original and subsequent designation. In the dimension sections the figure in parenthesis is the arithmetic mean of the measured morphological parameters. The geological ranges given for the species and genera are after Sarjeant (1967) unless otherwise stated, and the affinities are after Wall and Dale (1968).

Division PYRRHOPHYTA Pascher
Class DINOPHYCEAE Pascher
Order PERIDINIALES (Schutt) Lindemann

Cyst-Family GONYAULACYSTACEAE Sarjeant and Downie 1966
Genus APTEODINIUM Eisenack 1958

Type species. Apteodinium granulatum Eisenack 1958; O.D.

Apteodinium sp. A

Plate 84, fig. 2

The specimens compare quite favourably with *A. maculatum* Eisenack and Cookson (1960), except in the possession of a large prominent apical horn and in the style of 'ornamentation'; and with *A. tamboviensis* Vozzhennikova (1967), except in lacking a sulcus. Its affinities are gonyaulacacean with the apteodinioid lineage.

Figured material. Loc. 11, 7 (2) at 104·0–40·6. The last two figures refer to the sample number at the locality and the slide on which the specimen is to be found.

Dimensions. Range: Length 98·0 (112·5) 127·0 μ; breadth 98·0 (99·0) 100·0 μ. Two specimens observed.

Cyst-Family Uncertain
Genus DICONODINIUM Eisenack and Cookson 1960

Type species. Diconodinium multispinum (Deflandre and Cookson) Eisenack and Cookson (1960); O.D.

Wall and Dale (1968) regard the genus as having a precingular archeopyle and affinities with the Gonyaulacaceae, whereas Davey (1969*b*) prefers to include it with the Cyst-Family Deflandreaceae (of peridiniacean affinities). A precingular archeopyle is demonstrated here.

Diconodinium firmum sp. nov.

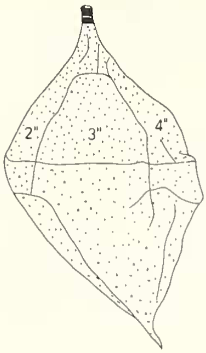
Plate 84, figs. 8, 9, 15, text-fig. 6

Derivation of name. Latin *firmum*—meaning solid, with reference to the structure of the distal extremity of the apical horn.

Diagnosis. Proximate cyst, commonly fusiform in shape, consisting of autophragm or two wall layers very closely adpressed. Test finely granulate. Epitract extends into an apical horn having a solid distal tip which may be oblate, acuminate, or bifurcate. The antapical horn always acuminate, and hollow throughout. The cingulum conspicuous and takes the form of a slight laevorotatory helicoid. Tabulation not usually seen. Archeopyle precingular of the P type (Evitt 1967), and rounded polygonal in shape. (Pl. 84, figs. 5, 6.)

Description. The granules on the walls are of variable size, usually fairly fine, but always conspicuous. The solid apical tip appears to have a definite structure (Pl. 84, fig. 15). It was often seen to be banded but its exact nature must await further study.

The cingulum is displaced by less than one-quarter of its width. Very little variation was seen in this cyst species except as documented in dimensions and in the nature of the apical tip.



TEXT-FIG. 6. *Diconodinium firmum* sp. nov. Semidiagrammatic sketch of the holotype. ×*c*. 1000.

Figured material. Holotype: Loc. 3, 7 (2) at 98·0–32·9; Bearpaw Formation, Campanian, southern Alberta. Loc. 2, 39 (1) at 108·0–30·3.

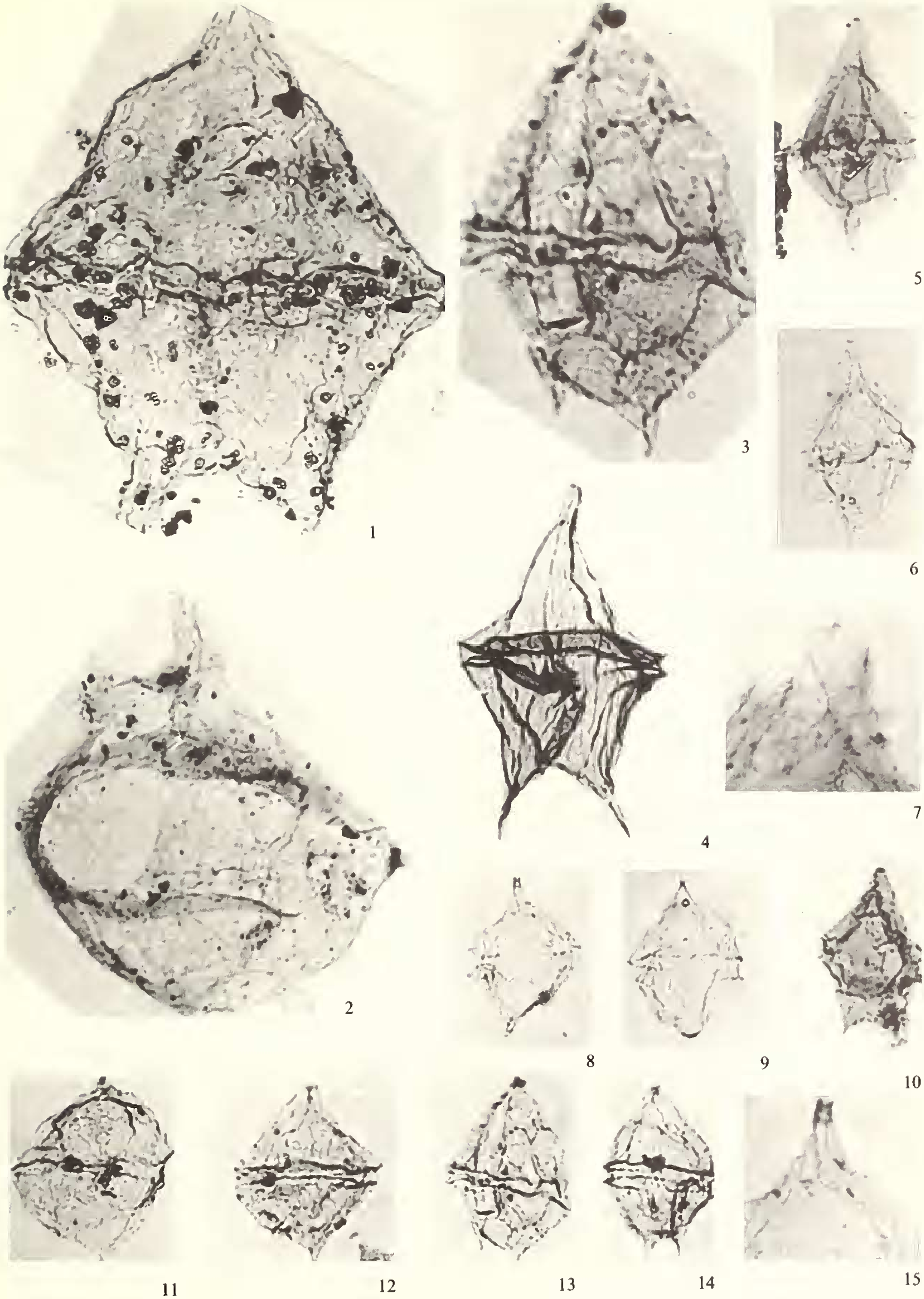
Dimensions. Holotype: Length 42·0 μ; breadth 29·0 μ. Range: Length 36·0 (42·7) 50·0 μ; breadth 18·0 (29·3) 32·0 μ. Fifty specimens measured, out of a studied population of sixty-four.

Remarks. This species is characterized by its shape and the solid structure at the distal extremity of the apical horn. It appears close to *Diconodinium rhombiformis* Vozzhennikova 1967 but is different in its lack of a distinct tabulation and the lack of small gonal processes in the cingular region. Although the archeopyle was rarely observed the conspicuous nature of plate 3″ also suggests that the archeopyle is formed by the loss of this plate. The species has gonyaulacacean affinities with apteodinioid lineage.

EXPLANATION OF PLATE 84

All figures at a magnification of ×600 unless otherwise stated.

Fig. 1. *Lejeunia ampla* sp. nov., holotype, dorsal view. Fig. 2. *Apteodinium* sp. A, oblique dorsal view, showing the archeopyle and surface ornamentation. Fig. 3. *Lejeunia parva* sp. nov., detail of specimen with the tabulation. ×*c*. 1800. Fig. 4. *Lejeunia tricuspis* (Wetzel) comb. nov., dorsal view. Fig. 5. *Spinidinium clavum* sp. nov., dorsal view. Fig. 6. *Spinidinium clavum* sp. nov., holotype, dorsal view. Fig. 7. *Lejeunia ampla* sp. nov., holotype, detail of apex with the ?apical archeopyle. ×*c*. 1800. Fig. 8. *Diconodinium firmum* sp. nov., holotype, dorsal view. Fig. 9. *Diconodinium firmum* sp. nov., dorsal view showing the archeopyle. Fig. 10. *Spinidinium clavum* sp. nov., a specimen with two well-developed antapical horns. Fig. 11. *Diconodinium arcticum* Manum and Cookson, dorsal view. Fig. 12. *Lejeunia parva* sp. nov., lateral view showing a lack of an antapical horn. Fig. 13. *Lejeunia parva* sp. nov., dorsal view of specimen showing tabulation. Fig. 14. *Lejeunia parva* sp. nov., holotype, ventral view. Fig. 15. *Diconodinium firmum* sp. nov., holotype, detail of the apex. ×*c*. 1800.



HARLAND, Campanian microfossils

Diconodinium arcticum Manum and Cookson 1964

Plate 84, fig. 11

1964 *Diconodinium arcticum* Manum and Cookson; 18–19, pl. 6, figs. 1–4.

The granulation on the surface of the test varied from coarse to fine in the specimens observed. It was also noted that they are smaller than those described by Manum and Cookson (1964). They cannot be compared to *D. glabrum* Eisenack and Cookson (1960) because they lack a clearly defined sulcus and differ in the nature of the 'ornamentation'. *D. arcticum* has an Upper Cretaceous range. Its affinities are gonyaulacacean with the apteodinioid lineage.

Figured material. Loc. 3, 1 (2) at 103·6–37·1.

Dimensions. Range: Length 30·0 (41·1) 57·0 μ; breadth 20·0 (26·3) 37·0 μ. Fifty specimens measured, out of a studied population of seventy-three.

Genus LEJEUNIA Gerlach 1961

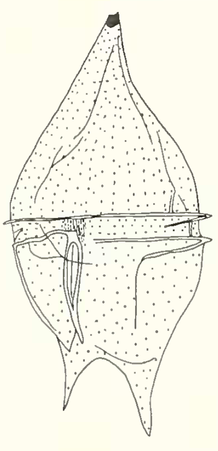
Type species. Lejeunia hyalina Gerlach 1961; O.D.

Lejeunia parva sp. nov.

Plate 84, figs. 3, 12–14, text-fig. 7

Derivation of name. Latin *parva*—meaning small, with reference to the size of the cyst.

Diagnosis. Proximate cyst, elongate to rhomboidal, made up of autophragm. Test granulate. Epitract elongated into an apical horn which is distally oblate or indented.



TEXT-FIG. 7. *Lejeunia parva* sp. nov. Semidiagrammatic sketch of the holotype. ×*c.* 1200.

Hypotract carries two antapical horns, one of which larger than the other; both distally acuminate. Cingulum, delimited by raised sutures, is planar to a slightly laevorotatory helicoid. Tabulation ?4′, 1a, ?7″, 4–?‴, 2⁗. Archeopyle not observed.

Figured material. Holotype: Loc. 3, 3 (2) at 99·0–31·9; Bearpaw Formation, Campanian, southern Alberta. Loc. 3, 3 (1) at 97·0–49·2. Loc. 3, 1 (1) at 103·0–36·7.

Dimensions. Holotype: Length 45·0 μ; breadth 30·0 μ. Range: Length 34·0 (44·4) 57·0 μ; breadth 25·0 (35·5) 41·0 μ. Twenty specimens measured, the number of specimens studied.

Description. Apical horn has a thickened structure which may or may not be solid, but invariably shows a suture apparently bisecting the horn. The antapical horns may be well developed or one may appear as a swelling. The tabulation variously developed and where present is delimited by raised sutures. One specimen seen with a complete tabulation. The cingulum, usually conspicuous and approximately three microns wide, may contain granular elements that appear aligned parallel to the longitudinal axis of the cyst. Plate 3″ of the tabulation large and conspicuous. Range of variation within this species is not great. The specimen with the tabulation not typical for this species and so not chosen as the holotype.

Remarks. This species is similar to that of *L. tenella* Morgenroth 1966. His specimens, however, lack all trace of tabulation and are larger and more rhomboidal in shape. It is also similar to *Palaeoperidinium cretaceum* Pocock but differs in being smaller and in not having an endoblast. It has possible peridiniacean affinities.

Lejeunia tricuspis (Wetzel) comb. nov.

Plate 84, fig. 4

1933 *Peridinium tricuspis* Wetzel; 166, pl. 2, fig. 14.

The Bearpaw specimens compare well with those of Wetzel (1933). The author considers that *Lejeunia kozlowskii* Gorka 1963 is a junior synonym. Gorka (1963) figures both *L. kozlowskii* and *L.* cf. *tricuspis*. It appears that any difference between the two can be accommodated by specific variation. *L. tricuspis* has a geological range of Santonian-Maestrichtian, and its affinities may be peridiniacean.

Figured material. Loc. 13, 13 (1) at 99·0–29·9.

Dimensions. Range: Length 80·0 (104·3) 135·0 μ; breadth 52·0 (73·8) 95·0 μ. Sixteen specimens measured, the number of specimens studied.

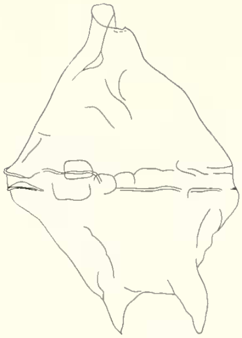
Lejeunia ampla sp. nov.

Plate 84, figs. 1, 7, text-fig. 8

Derivation of name. Latin *ampla*—meaning large, with reference to the overall size of this species.

Diagnosis. Proximate cyst, rhomboidal in shape, probably made up of autophragm only. Test granulate, scabrate and/or reticulate. No tabulation visible. Cingulum usually conspicuous, planar, approximately 5 microns wide, delimited by raised sutures. Single apical horn, distally oblate; two antapical horns one of which generally larger than the other. Archeopyle apical.

Figured material. Holotype: Loc. 3, 13 (1) at 95·8–37·0; Bearpaw Formation, Campanian, southern Alberta.



TEXT-FIG. 8. *Lejeunia ampla* sp. nov. Semidiagrammatic sketch of the holotype. ×*c*. 300.

Dimensions. Holotype: Length 149·0 μ; breadth 108·0 μ. Range: Length 70·0 (116·3) 154·0 μ; breadth 68·0 (97·0) 108·0 μ. Fifty specimens measured out of a studied population of eighty-nine.

Description. It is possible that a second wall layer, closely adpressed, is present. Only one or two specimens show an apical archeopyle. Norris (*pers. comm.*) has observed transapical archeopyles in specimens with the same gross morphology. The Bearpaw specimens appear to have had one or two antapical plates making up the operculum. The antapical horns distally evexate and one was seen to carry small spinules.

Remarks. This species differs from *L. tricuspis* in lacking the vertical striations, the acuminate antapical horns, and the coarse 'ornamentation'. Doubt is expressed in the generic assignment because of uncertainties in the nature of the archeopyle in this species and in the genus. The archeopyle as seen in the holotype is perfectly clear and does not appear to be of accidental origin. Evitt (*pers. comm.*) has commented on the resemblance of the small folds, often observed on the test of these cysts, to growth lines such as those exhibited by *Palaeoperidinium pyrophorum* (Ehrenberg). Its affinities are unknown.

Genus SPINIDINIUM Cookson and Eisenack 1962*b*

Type species. Spinidinium styloniferum Cookson and Eisenack 1962*b*; O.D.

Spinidinium is characterized by the possession of 'spines'. It is, however, morphologically similar to *Deflandrea* in that the genus is cavate and possesses an intercalary archeopyle. Wilson (1967) has placed certain spiny specimens in the genus *Deflandrea* and certainly a review of the situation is indicated as *Deflandrea* is presently defined to include only forms with smooth or granulate tests.

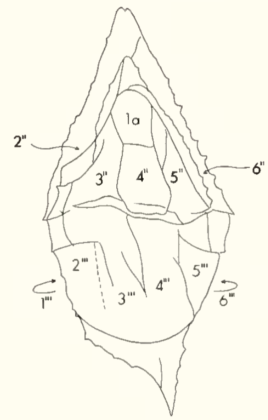
Spinidinium clavum sp. nov.

Plate 84, figs. 5, 6, 10, text-fig. 9

Derivation of name. Latin *clavum*—meaning spike, with reference to the development of short, acuminate processes along the sutural crests.

Diagnosis. Cavate cyst, fusiform in shape, made up of two wall layers closely adpressed except at the apex and antapex where pericoels may be evident. Test usually smooth with the presence of occasional discrete granules. Epitract slightly more conical than the hypotract. Prominent apical horn, tapering with a bifid tip; antapical horns acuminate. Sutural ridges, up to 5 μ tall, carry short oblate and acuminate processes. Certain plate areas of the tabulation may be delimited due to sutural development. A tabulation ?4′, 1a, ?7″, ?4c, 5–6‴, ?2⁗ indicated. Cingulum planar, sulcus conspicuous extending on to both the epitract and hypotract. Archeopyle indeterminate, but it is almost certain that loss of the conspicuous intercalary plate forms the archeopyle.

Description. Cavate cyst often appears proximate because of poor pericoel development. The apex appears to be made up of four apical plates which are separated by large sutural ridges, characteristic of this species. These ridges add to the prominence of the apex. The crests of the ridges carry small oblate and acuminate processes. The precingular plate series appears to consist of five to seven plates, of which plate 4″ is conspicuous and polygonal in shape; directly above this plate there is a single rectangular anterior intercalary plate. The cingulum is often the focus for folding and crumpling of the cyst. The post-cingular plate series appears to comprise five or six plates but only certain indeterminate plate boundaries were seen. The hypotract is more rounded than the epitract. The sutural crests are better developed on the epitract than on the hypotract. The range of variation of this species is seen in Plate 84. The most variable feature is the size of the endoblast in relation to periblast.



TEXT-FIG. 9. *Spinidinium clavum* sp. nov. Semi-diagrammatic sketch of the holotype. × *c.* 1000.

Figured material. Holotype: Loc. 11, 1 (1) at 95·0–40·1; Bearpaw Formation, Campanian, southern Alberta. Loc. 5, 1 (2) at 94·7–38·0. Loc. 5, 1 (1) at 104·0–32·0.

Dimensions. Holotype: Length 51·0 μ; breadth 29·0 μ. Range: Length 40·0 (45·3) 60·0 μ; breadth 20·0 (26·0) 35·0 μ. Seventeen specimens observed.

Remarks. This species is characterized by the nature of the large sutural ridges. It is similar to *Palaeoperidinium caulleryi* Deflandre 1934 which Deflandre (1966) considers to be a member of the genus *Diconodinium.* It was not, however, formally combined (re Article 33 of I.C.B.N.). It has peridiniacean affinities with the deflandreoid lineage.

Cyst-Family MICRODINIACEAE Eisenack emend. Sarjeant and Downie 1966
Genus MICRODINIUM Cookson and Eisenack emend. Sarjeant 1966

Type species. Microdinium ornatum Cookson and Eisenack 1960; O.D.

Microdinium cf. *irregulare* Clarke and Verdier 1967

Plate 85, figs. 15, 16

1967 ?*Microdinium irregulare* Clarke and Verdier; 65–66, pl. 7, figs. 5–8, text-fig. 27.

Description. Proximate cyst, spheroidal to ovoidal in shape, composed of periphragm and endophragm. The periphragm makes up the large and conspicuous sutural crests.

Cyst microgranulate to granulate except for the crests which are smooth. Tabulation present. Cingulum 3–4 microns wide, planar or weakly helicoidal in nature. Epitract small in comparison to the hypotract, the tabulation difficult to decipher because of the granules and crests but plates 6''', 1p, 1'''' were observed. Epitractal details are especially difficult to see. The archeopyle apical of Ā type, and probably formed by the loss of three or four apical plates (Evitt, *pers. comm.*).

Figured material. Loc. 11, 1 (2) at 100·0–43·3. Loc. 10, 4 (2) at 94·0–32·6.

Dimensions. Range: Length 24·0 (34·5) 39·0 μ; breadth 26·0 (32·6) 38·0 μ. Thirty-six specimens observed.

Remarks. These specimens compare well with those described by Clarke and Verdier (1967). This species has a geological range Cenomanian–Santonian. It has gonyaulacacean affinities with the lithodinioid lineage.

Cyst-Family Uncertain

Genus DINOGYMNIUM Evitt, Clarke and Verdier 1967

Type species. Dinogymnium acuminatum Evitt, Clarke and Verdier 1967; O.D.

Dinogymnium cf. *albertii* Clarke and Verdier 1967

Plate 85, fig. 18

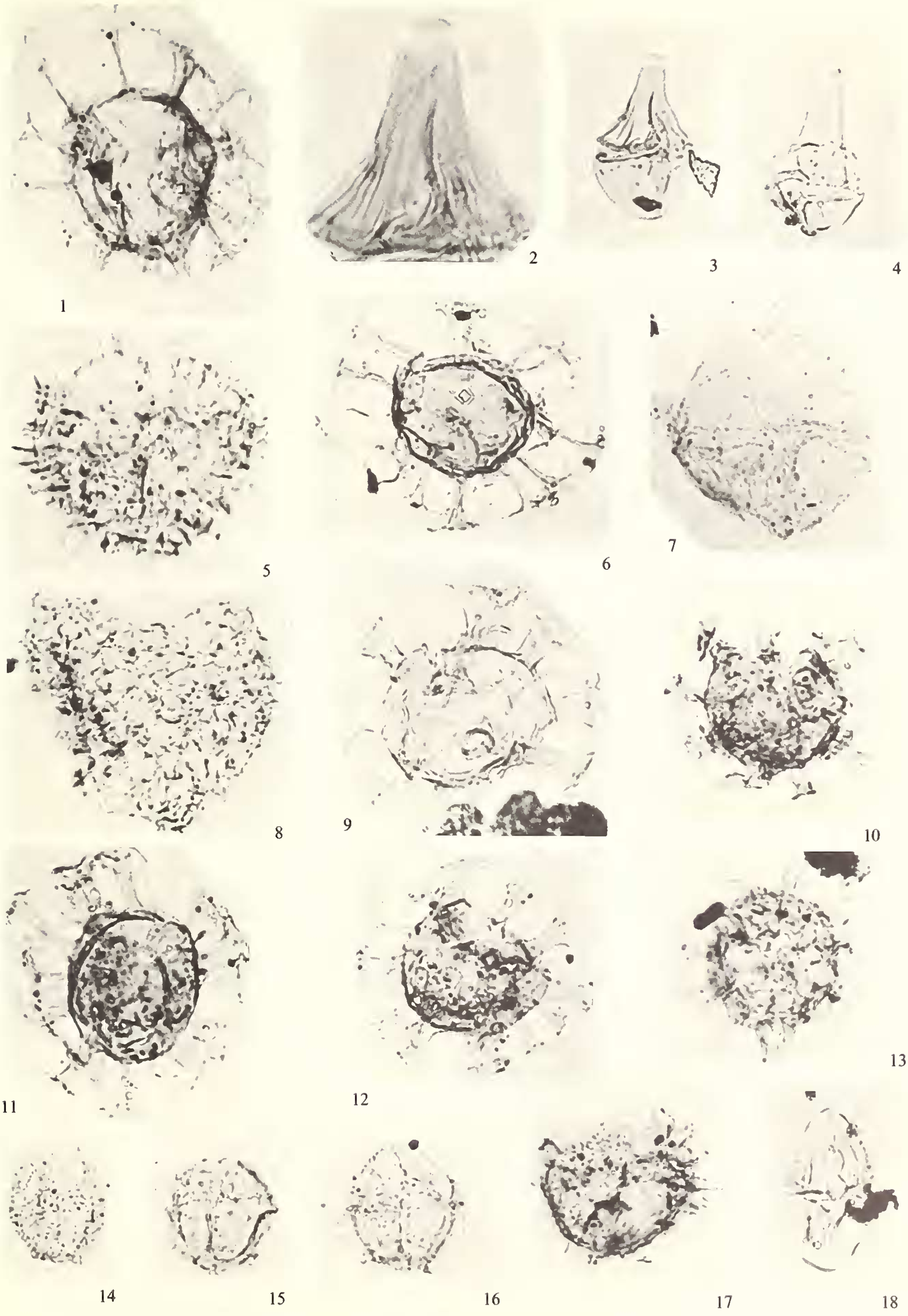
1967 ?*Dinogymnium albertii* Clarke and Verdier; 33, pl. 17, figs. 3, 4, text-fig. 13.

Description. Proximate cyst, subspheroidal to ovoidal in shape, the epitract more conical than the hypotract, made up of two wall layers closely adpressed. Test carries a number of longitudinal grooves, that are commoner on the epitract than on the hypotract. In addition, the test perforated by many punctae (wall canals). Tabulation not present except for a very conspicuous deep cingulum which is 4 microns wide,

EXPLANATION OF PLATE 85

All figures at a magnification of ×600 unless otherwise stated.

Fig. 1. *Hystrichosphaeridium dowlingii* sp. nov., ventral view, holotype, showing the archeopyle and the nature of the processes. Fig. 2. *Dinogymnium longicornis* (Vozzhennikova) comb. nov., detail of the apex. ×*c*. 1800. Fig. 3. *Dinogymnium longicornis* (Vozzhennikova) comb. nov., ventral view of a specimen with a low cingulum index. Fig. 4. *Dinogymnium longicornis* (Vozzhennikova) comb. nov., lateral view of a specimen with a high cingulum index. Fig. 5. *Canningia senonica* Clarke and Verdier, dorsal view. Fig. 6. *Hystrichosphaeridium* cf. *arborispinum* Davey and Williams, lateral view. Fig. 7. ?*Uvatodinium* cf. *nasutum* Vozzhennikova, dorsal view. Fig. 8. *Canningia senonica* Clarke and Verdier, lateral view. Fig. 9. *Hystrichosphaeridium salpingophorum* (Deflandre) emend. Davey and Williams, lateral view. Fig. 10. *Hystrichosphaeridium tubiferum* var. *brevispinum* Davey and Williams, lateral view. Fig. 11. *Hystrichosphaeridium* cf. *arborispinum* Davey and Williams, ventral view. Fig. 12. *Hystrichosphaeridium salpingophorum* (Deflandre) emend. Davey and Williams, lateral view. Fig. 13. ?*Coronifera oceanica* Cookson and Eisenack, lateral view. Fig. 14. ?*Membranosphaera* cf. *maastrichtica* Samoylovich *ex.* Norris and Sarjeant emend. Drugg, lateral view. Fig. 15. *Microdinium* cf. *irregulare* Clarke and Verdier, lateral view. Fig. 16. *Microdinium* cf. *irregulare* Clarke and Verdier, lateral view showing well-developed smooth sutural crests. Fig. 17. *Cleistosphaeridium* sp. A, lateral view. Fig. 18. *Dinogymnium* cf. *albertii* Clarke and Verdier, lateral view.



HARLAND, Campanian microfossils

and takes the form of a laevorotatory helicoid. The test is often crumpled along this feature. Displacement approximately equal to half the width of the cingulum. Sulcus also present but only on the hypotract. Archeopyle apical, regarded as miscellaneous by Evitt (1967), formed by loss of a ? single plate at the very tip of the epitract.

Figured specimen. Loc. 9, 37 (1) at 105·7–42·0.

Dimensions. Range: Length 40·0 (41·3) 42·0 μ; breadth 20·0 (22·0) 25·0 μ, cingulum index 50·0 (52·3) 55·0. Three specimens observed.

Remarks. This species is compared to *D. albertii* Clarke and Verdier 1967 by virtue of the presence of punctae and in its general form, but it is smaller in size. It was previously recorded from the Santonian by Clarke and Verdier 1967. In general morphology the genus closely resembles the modern genus *Gymnodinium*, with which it has often been confused. The affinities of this cyst are as yet unknown.

Dinogymnium longicornis (Vozzhennikova) nov. comb.

Plate 85, figs. 2–4

1967 *Gymnodinium longicornis* Vozzhennikova; 46, pl. 1, fig. 8, pl. 3, fig. 6, pl. 4, figs. 6*a*, 6*b*, 7.

Description. Proximate cyst, ovoidal to markedly elongate, made up of two closely adpressed wall layers. Test carries some longitudinal grooves and a fine micropunctation which is better developed in some specimens than others. The epitract conical to very elongate, drawn out into a long apical horn. The hypotract always hemispheroidal. A conspicuous cingulum always present, approximately 2 microns wide, in the form of a laevorotatory helicoid which is displaced by up to twice its width. A sulcus is present on the hypotract only. Faint sutural ridges are sometimes present, delimiting a possible tabulation; a possible reflected plate 1p was observed in one specimen. Archeopyle apical, typical for the genus.

Figured material. Loc. 9, 20 (3) at 102·0–29·3. Loc. 9, 24 (3) at 107·9–36·3.

Dimensions. Range: Length 39·0 (49·4) 59·0 μ; breadth 19·0 (27·3) 33·0 μ, cingulum index 58·0 (65·75) 75·0. Eleven specimens studied.

Remarks. This species is very similar to that figured by Vozzhennikova (1967); there can be no doubt that the species belongs to the genus *Dinogymnium* as in Vozzhennikova's figures the archeopyle is perfectly evident. The specimens from the Bearpaw Formation seem more variable than those of Vozzhennikova (1967) and are generally smaller. The Russian specimens are Senonian in age and were recovered from western Siberia. Its affinities are unknown.

Cyst-Family FROMEACEAE Sarjeant and Downie 1966
Genus MEMBRANOSPHAERA Samoylovich *ex.* Norris and Sarjeant emend. Drugg 1967

Type species. Membranosphaera maastrichtica Samoylovich *ex.* Norris and Sarjeant, 1965; S.D.

?*Membranosphaera* cf. *maastrichtica* Samoylovich *ex.* Norris and Sarjeant emend. Drugg 1967

Plate 85, fig. 14

1961 ?*Membranosphaera maastrichtica* Samoylovich (in Samoylovich *et al.* 252, pl. 83, figs. 1, 2.
1965 ?*Membranosphaera maastrichtica* Samoylovich *ex.* Norris and Sarjeant; 40.
1967 ?*Membranosphaera maastrichtica* Samoylovich *ex.* Norris and Sarjeant emend. Drugg; 29–30, pl. 5, figs. 12, 13.

Description. Proximate cyst, spheroidal to ovoidal in shape, composed of endophragm and periphragm. The endophragm makes up small cylindrical capitate processes that appear to support an outer membraneous periphragm. A faint trace of the cingulum observed; it appears planar, approximately three microns in width and is delimited by areas devoid of endophragmal processes. No other tabulation discernible. The archeopyle apical, possibly of a type formed by loss of a single apical plate; the sulcal notch was observed.

Figured material. Loc. 10, 5 (3) at 103·0–34·4.

Dimensions. Range: Length 28·0 (30·0) 32·0 μ; breadth 27·0 (27·5) 28·0 μ. Two specimens observed.

Remarks. The Bearpaw specimens differ from those of Drugg (1967) in possessing a faint cingulum and a smaller apical archeopyle. This species had a previous geological range of Maestrichtian–Danian (Drugg 1967). Its affinities are unknown.

Cyst-Family CANNINGIACEAE Sarjeant and Downie 1966
Genus CANNINGIA Cookson and Eisenack 1960

Type species. Canningia reticulata Cookson and Eisenack 1960; O.D.

Canningia senonica Clarke and Verdier 1967

Plate 85, figs. 5, 8

1967 *Canningia senonica* Clarke and Verdier; 20, 21, pl. 1, figs. 12–14, text-fig. 7.

It was noticed in the specimens attributed to this species that there was considerable variation with regard to process development and the apparent reticulation. This species was previously reported from the Senonian of the Isle of Wight, England, by Clarke and Verdier (1967). It has gonyaulacacean affinities with the lithodinioid lineage.

Figured material. Loc. 11, 7 (3) at 103·0–30·0. Loc. 9, 39 (1) at 109·0–28·2.

Dimensions. Range: Length 36·0 (48·0) 67·0 μ; breadth 40·0 (51·5) 63·0 μ, the processes range in length from 2·0–8·0 μ. Four specimens observed.

Cyst-Family PYXIDIELLACEAE Sarjeant and Downie 1966
Genus UVATODINIUM Vozzhennikova 1963

Type species. Uvatodinium nasutum Vozzhennikova 1963; O.D.

?*Uvatodinium* cf. *nasutum* Vozzhennikova 1963

Plate 85, fig. 7

1963 ?*Uvatodinium nasutum* Vozzhennikova; 182, figs. 13*a*, 13*b*.

Description. Proximate cyst, subspheroidal in shape, composed of periphragm and endophragm closely adpressed; the former makes up the 'ornamentation'. Test granulate. Epitract bears an apical horn, which is distally evexate, and a distinct 'shoulder'. The hypotract carries a slight antapical boss. The cingulum conspicuous, delimited by raised sutures, takes the form of a laevorotatory helicoid and displaced by half the width of the cingulum which is four to five microns wide. A sulcus present, delimited by raised sutures, and confined to the hypotract. No other tabulation present. Archeopyle intercalary of the I type.

Figured material. Loc. 11, 7 (1) at 99·0–29·6.

Dimensions. Range: Length 61·0 (68·0) 75·0 μ; breadth 54·0 (57·6) 60·0 μ. Three specimens observed.

Remarks. These specimens compare quite well with those illustrated by Vozzhennikova (1967) but lack the coarse reticulation; although in pl. 8, fig. 4 of Vozzhennikova (1967) the reticulation is not at all obvious. This species has previously been recorded from the Palaeocene (Vozzhennikova 1967). Its affinities are unknown.

Cyst-Family HYSTRICHOSPHAERIDIACEAE Evitt emend. Sarjeant and Downie 1966
Genus HYSTRICHOSPHAERIDIUM Deflandre emend. Davey and Williams 1966*b*

Type species. Hystrichosphaeridium tubiferum (Ehrenberg) Deflandre 1937; O.D.

Hystrichosphaeridium cf. *arborispinum* Davey and Williams 1966*b*

Plate 85, figs. 6, 11

1966*b* ?*Hystrichosphaeridium arborispinum* Davey and Williams; 61, pl. 9, figs. 5, 10.

Description. Chorate cyst, subspheroidal to ovoidal in shape, made up of both periphragm and endophragm, the former making up the processes. Cyst smooth to microgranulate. The processes intratabular and reflect the tabulation 6″, 6c, 5‴, 1⁗; they are hollow, slender to latispinous, erect, cylindrical, and distally flared. The distal extremities recurved, digitate to serrate. In many specimens the processes appear fibrous. Additional cylindrical recurved and digitate sutural processes present in many specimens. The archeopyle apical of the $\bar{\text{A}}$ type.

Figured material. Loc. 11, 1 (3) at 93·0–30·5. Loc. 9, 39 (2) at 107·0–33·8.

Dimensions. Range: Long axis of cyst 29·0 (40·0) 52·0 μ; short axis of cyst 30·0 (38·35) 55·0 μ, processes range in length from 11 to 25 μ. Twenty specimens observed.

Remarks. This species is fairly common in the Bearpaw assemblages and may be recognized by the character of its processes. It had a geological range Lower Barremian–Middle Barremian. Its affinities are gonyaulacacean in the hystrichosphaeridioid lineage.

Hystrichosphaeridium dowlingii sp. nov.

Plate 85, fig. 1, text-fig. 10

Derivation of name. Named in honour of D. B. Dowling, one of the first geologists to work in southern Alberta.

Diagnosis. Chorate cyst, spheroidal in shape, made up of periphragm and endophragm. Test microgranulate. Tabulation 6″, 6c, 6‴, 1–2p, 1⁗. Processes hollow slender to latispinous, erect to curved, cylindrical, distally flared and fenestrate. Archeopyle of the $\bar{A}$ type.

TEXT-FIG. 10. *Hystrichosphaeridium dowlingii* sp. nov. Semidiagrammatic sketch of the holotype. × *c*. 1300.

Figured material. Holotype: Loc. 9, 39 (2), at 106·0–33·9; Bearpaw Formation, Campanian, southern Alberta.

Dimensions. Holotype: Long axis of cyst 44·0 μ; short axis of cyst 38·0 μ, processes range in length from 15 to 24 μ. Range: Long axis of cyst 25·0 (34·4) 46·0 μ; short axis of cyst 29·0 (34·0) 54·0 μ, processes range in length from 10 to 28 μ. Twelve specimens measured, the number of specimens studied.

Description. The periphragm makes up the processes which do not appear to connect to the interior of the cyst. Test 'ornament' does not extend on to the process shafts. The sulcal area devoid of all processes except for a group of two sulcal processes. A sulcal notch may also be seen in some specimens.

Remarks. This species is easily distinguishable from *H.* cf. *arborispinum* by the nature of the processes, i.e. fenestrate nature and lack of 'ornamentation' on the processes shafts. The test 'ornamentation' is also much coarser than that of *H.* cf. *arborispinum*. Its affinities are gonyaulacacean with the hystrichosphaeridioid lineage.

Hystrichosphaeridium tubiferum var. *brevispinum* Davey and Williams 1966*b*

Plate 85, fig. 10

1966*b* *Hystrichosphaeridium tubiferum* var. *brevispinum* Davey and Williams; 58, pl. 10, fig. 10.

This variety compares well with those specimens described by Davey and Williams (1966*b*). The Bearpaw specimens were, however, smaller in size with a slightly more variable process habit. The variety is characterized by process length, and had a range of Eocene (Davey and Williams 1966*b*). Its affinities are gonyaulacacean with the hystrichosphaeridioid lineage.

Figured material. Loc. 9, 39 (1) at 101·0–31·3.

Dimensions. Range: Long axis of cyst 25·0 (31·2) 38·0 μ; short axis of cyst 25·0 (30·6) 38·0 μ, processes range in length 6 to 15 μ. Twenty specimens observed.

Hystrichosphaeridium salpingophorum (Deflandre) Davey and Williams 1966*b*

Plate 85, figs. 9, 12

1935 *Hystrichosphaera salpingophora* Deflandre; 232, pl. 9, fig. 1.
1966*b* *Hystrichosphaeridium salpingophorum* (Deflandre) emend. Davey and Williams; 61, 62, pl. 10, fig. 6.

This species compares well with those specimens figured by Davey and Williams (1966*b*). There is an obvious morphological overlap with *H. tubiferum* var. *brevispinum* but usually the two species can be recognized. The species has a geological range of Upper Jurassic–Lower Eocene. Its affinities are gonyaulacacean with the hystrichosphaeridioid lineage.

Figured material. Loc. 9, 39 (2) at 99·0–36·0. Loc. 13, 5 (3) at 92·0–40·6.

Dimensions. Range: Length of long axis 31·0 (38·8) 44·0 μ; length of short axis 29·0 (35·75) 48·0 μ, processes range in length from 10 to 18 μ. Nine specimens observed.

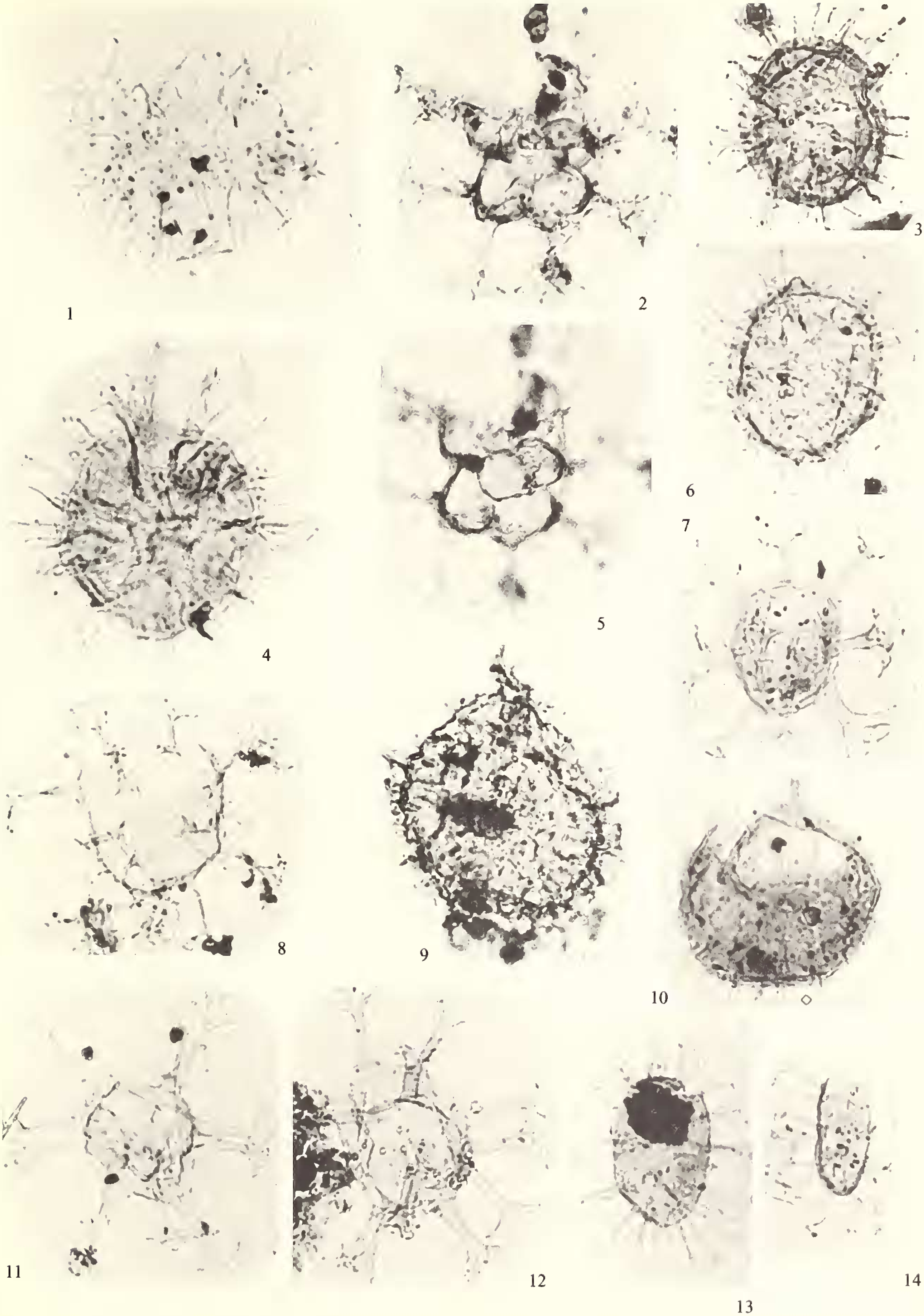
Genus CLEISTOSPHAERIDIUM Davey, Downie, Sarjeant and Williams 1966

Type species. Cleistosphaeridium diversispinosum Davey, Downie, Sarjeant and Williams 1966; O.D.

EXPLANATION OF PLATE 86

All figures at a magnification of ×600 unless otherwise stated.

Fig. 1. *Cleistosphaeridium diversispinosum* Davey *et al.*, lateral view. Fig. 2. Forma A, lateral view, showing nature of the archeopyle. Fig. 3. *Polysphaeridium subtile* Davey and Williams, orientation unknown. Fig. 4. *Exochosphaeridium pseudohystrichodinium* (Deflandre) emend. Davey, lateral view. Fig. 5. Forma A, lateral view, showing globular central body. Fig. 6. *Polysphaeridium subtile* Davey and Williams, ?lateral view showing apical boss. Fig. 7. *Oligosphaeridium anthophorum* (Cookson and Eisenack) Davey, lateral view. Fig. 8. *Oligosphaeridium anthophorum* (Cookson and Eisenack) Davey, ventral view. Fig. 9. *Exochosphaeridium* sp. A, lateral view. Fig. 10. *Exochosphaeridium* cf. *phragmites* Davey *et al.*, dorsal view. Fig. 11. *Oligosphaeridium pulcherrimum* (Deflandre and Cookson) Davey and Williams, lateral view. Fig. 12. *Oligosphaeridium pulcherrimum* (Deflandre and Cookson) Davey and Williams, lateral view. Fig. 13. *Tanyosphaeridium variecalamum* Davey and Williams, lateral view of specimen with many processes per plate area. Fig. 14. *Tanyosphaeridium variecalamum* Davey and Williams, lateral view of specimen with few processes per plate area.



HARLAND, Campanian microfossils

Cleistosphaeridium diversispinosum Davey, Downie, Sarjeant, and Williams 1966

Plate 86, fig. 1

1966 *Cleistosphaeridium diversispinosum* Davey *et al.*; 167, pl. 10, fig. 7.

Considerably more specific variation than that observed by Davey *et al.* (1966) is present within this species. The processes are variable in thickness, sinuosity, length, and in the structural diversity of their extremities. This species was previously recorded from the Eocene. Its affinities are unknown.

Figured material. Loc. 10, 5 (1) at 95·0–43·4.

Dimensions. Range: Length 35·0 (48·75) 57·0 μ; breadth 43·0 (52·25) 67·0 μ, processes range in length from 5 to 19 μ. Nine specimens observed.

Cleistosphaeridium sp. A

Plate 85, fig. 17

Description. Chorate cyst, subspheroidal in shape, made up of two wall layers; the periphragm makes up the processes. The test carries granules but no trace of tabulation could be discerned, as the processes appear randomly dispersed. The processes slender to latispinous, curved to sinuous, cylindrical to tapering. Most processes end in an equal distal bifurcation but others are acuminate and oblate. Archeopyle apical, of the $\bar{A}$ type.

Figured material. Loc. 3, 3 (1) at 98·0–46·5.

Dimensions. Range: Length 35·0 (39·0) 43·0 μ; breadth 39·0 (40·5) 42·0 μ, processes range in length from 8 to 11 μ. Two specimens observed.

Remarks. This species is similar to ?*Cleistosphaeridium flexuosum* Davey *et al.* 1966 but differs in process length and in the nature of the process extremities. Its affinities are unknown.

Genus CORONIFERA Cookson and Eisenack emend. Davey 1969*a*

Type species. Coronifera oceanica Cookson and Eisenack 1958; O.D.

?*Coronifera oceanica* Cookson and Eisenack 1958

Plate 85, fig. 13

1958 ?*Coronifera oceanica* Cookson and Eisenack; 45, pl. 12, figs. 5, 6.

Description. Proximate cyst, spheroidal in shape. Test composed of two wall layers closely adpressed of which the periphragm alone makes up the processes. Cyst wall microgranulate and covered by numerous processes, seemingly at random. The processes do not connect to the interior of the cyst and are slender, curved, cylindrical to tapering, and distally acuminate. No tabulation could be discerned. The cyst carries a single large antapical process which is latispinous, erect, distally open with an entire or denticulate margin. This process is very characteristic of the species and genus. No archeopyle observed.

Figured material. Loc. 1, 28 (1) at 106·7–46·0.

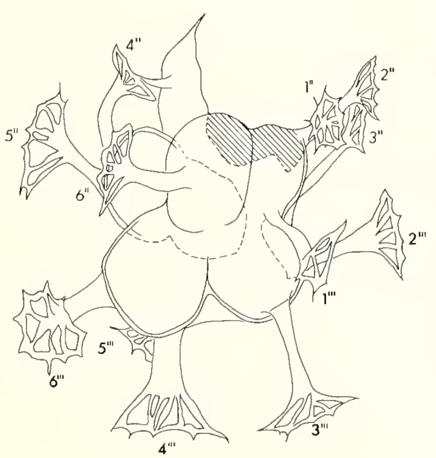
Dimensions. Range: Length 33·0 (37·5) 42·0 μ; breadth 31·0 (40·5) 50·0 μ, the processes range in length from 4–10 μ. Two specimens observed.

Remarks. The specimens under consideration differ from those of Davey (1969*a*) in lacking any kind of sutural ridges or clear apical processes. This is probably a consequence of specific variation. Lack of the presence of an archeopyle casts some doubt on the identification of this species. The presence of an Ā archeopyle would suggest that these specimens be placed in the genus *Diphyes* Cookson 1965. *C. oceanica* had a geological range Albian–Cenomanian. It probably has gonyaulacacean affinities by virtue of the single antapical process, suggesting the possession of a single antapical plate. Millioud (1969) reported the presence of a precingular archeopyle in a new species of *Coronifera* from the Upper Hauterivian of Angles, SE. France, indicating that *Coronifera* should be attributed to the hystrichodinioid lineage.

Forma A

Plate 86, figs. 2, 5, text-fig. 11

Description. Chorate cyst, ovoidal to elongate in shape. Test consists of a thick (1·0–1·5 microns) endophragm and a thin periphragm. Test smooth to microgranulate. Endoblast appears made up of discrete chambers giving the cyst a globate appearance. Two whorls of lobes present separated by a cingular groove in the form of a laevorotatory helicoid. Processes intratabular, reflecting a possible tabulation of ?7″ and 5 or 6‴. They do not connect to the interior of the cyst and are constructed of periphragm. No antapical processes present. Archeopyle apical with an attached operculum, possibly of the Āa type.



TEXT-FIG. 11. Forma A. Semidiagrammatic sketch. ×*c*. 1200.

Figured material. Loc. 1, 36 (3) at 107·2–35·9.

Dimensions. Range: Length 32·0 (37·5) 43·0 μ; breadth 25·0 (29·5) 34·0 μ, processes range in length from 20 to 25 μ. Two specimens observed.

Remarks. These cysts are peculiar in the structure of the central body which appears to be made up of discrete chambers. Two whorls are present, one at either side of the cingulum. A single chamber is centrally placed on the ventral surface of the cyst and it may be equivalent to reflected plate 7″. The laevorotatory helicoidal cingulum divides the two whorls. It is of interest to note that no antapical process is present.

There is, however, a possible accessory sulcul process. Also of interest is the opening in reflected plate 2‴. It appears that the archeopyle has been formed by partial loss of the apical plate series with a single opercular piece remaining. It was difficult to observe the exact relationship of this operculum ? to the archeopyle. Evitt (*pers. comm.*) considers that the lobate nature of this cyst is due to deformation as the result of the growth of pyrite sphaerules. Its affinities are unknown.

Genus OLIGOSPHAERIDIUM Davey and Williams 1966*b*

Type species. Oligosphaeridium complex (White) Davey and Williams 1966*b*; O.D.

Oligosphaeridium anthophorum (Cookson and Eisenack) Davey 1969*a*

Plate 86, figs. 7, 8

1958 *Hystrichosphaeridium anthophorum* Cookson and Eisenack; 43, 44, pl. 11, figs. 12, 13.
1969*a* *Oligosphaeridium anthophorum* (Cookson and Eisenack) Davey; 147, 148, pl. 5, figs. 1–3.

These specimens compare well with those of Cookson and Eisenack (1958) except that they are smaller and the processes appear to be a little more slender. The species had a previously described geological range Oxfordian–Albian, and has gonyaulacacean affinities with the hystrichosphaeridioid lineage.

Figured material. Loc. 3, 7 (3) at 105·7–39·7. Loc. 9, 37 (1) at 92·0–28·2.

Dimensions. Range: Length of long axis 24·0 (33·3) 45·0 μ; length of short axis 21·0 (31·8) 43·0 μ, the processes range in length from 12 to 34 μ. Sixteen specimens observed.

Oligosphaeridium pulcherrimum (Deflandre and Cookson) Davey and Williams 1966*b*

Plate 86, figs. 11, 12

1955 *Hystrichosphaeridium pulcherrimum* Deflandre and Cookson; 270, 271, pl. 1, fig. 8, text-figs. 21, 22.
1966*b* *Oligosphaeridium pulcherrimum* (Deflandre and Cookson) Davey and Williams; 75, 76, pl. 10, fig. 9, pl. 11, fig. 5.

These specimens agree closely to those of Deflandre and Cookson (1955) except in size; the Bearpaw material being smaller. The geological range of this species is Valanginian–Lower Eocene. It has gonyaulacacean affinities with the hystrichosphaeridioid lineage.

Figured material. Loc. 11, 9 (1) at 103·0–44·6. Loc. 9, 39 (2) at 101–31·9.

Dimensions. Range: Length of long axis 20·0 (34·9) 43·0 μ; length of short axis 23·0 (32·9) 40·0 μ, processes range in length from 9 to 37 μ. Fifty specimens measured, from a studied population of seventy-four.

Genus POLYSPHAERIDIUM Davey and Williams 1966*b*

Type species. Polysphaeridium subtile Davey and Williams 1966*b*; O.D.

Polysphaeridium subtile Davey and Williams 1966*b*

Plate 86, figs. 3, 6

1966*b* *Polysphaeridium subtile* Davey and Williams; 92, pl. 11, fig. 1.

These specimens compare well with those of Davey and Williams (1966*b*) except in the morphology of the distal tip of the processes; those of Davey and Williams (1966*b*) are more serrate. There is, however, a certain amount of variability in the Bearpaw specimens suggesting that these morphological variations may all be encompassed in the concept of this species. *P. subtile* has a geological range of Coniacian–Middle Miocene, and has gonyaulacacean affinities probably with the hystrichosphaeridioid lineage.

Figured material. Loc. 3, 7 (2) at 107·2–42·6. Loc. 9, 39 (2) at 97·0–32·3.

Dimensions. Range: Length of long axis 22·0 (38·5) 50·0 μ; length of short axis 30·0 (35·9) 47·0 μ, processes range in length from 5 to 14 μ. Twenty specimens observed.

Genus TANYOSPHAERIDIUM Davey and Williams 1966*b*

Type species. Tanyosphaeridium variecalamum Davey and Williams 1966*b*; O.D.

Tanyosphaeridium variecalamum Davey and Williams 1966*b*

Plate 86, figs. 13, 14

1966*b* *Tanyosphaeridium variecalamum* Davey and Williams; 98, 99, pl. 6, fig. 7, text-fig. 20.

A tentative tabulation from specimens where the processes appear to be restricted to one per plate area is 6″, 6c, 6–7‴, 1p, 1⁗. These specimens compare well in all respects to those figured by Davey and Williams (1966*b*). This species had a previously recorded geological range of Albian–Cenomanian. The possession of a single reflected antapical plate suggests a gonyaulacacean affinity for this cyst, probably with the hystrichosphaeridioid lineage.

Figured material. Loc. 9, 39 (3) at 106·0–38·0, and 109·0–40·9.

Dimensions. Range: Length 25·0 (31·4) 37·0 μ; breadth 15·0 (22·3) 42·0 μ, length of processes ranges from 6 to 13 μ. Seven specimens observed.

Cyst-Family EXOCHOSPHAERIDIACEAE Sarjeant and Downie emend. Davey 1969*c*

Genus EXOCHOSPHAERIDIUM Davey, Downie, Sarjeant and Williams 1966

Type species. Exochosphaeridium phragmites Davey, Downie, Sarjeant, and Williams 1966; O.D.

Exochosphaeridium cf. *phragmites* Davey, Downie, Sarjeant, and Williams 1966

Plate 86, fig. 10

1966 *Exochosphaeridium phragmites* Davey, Downie, Sarjeant, and Williams; 165, 166, pl. 2, figs. 8–10.

Description. Chorate cyst, subspheroidal in shape, made up of periphragm and endophragm closely adpressed; the former makes up the processes. Test granulate.

A large apical process present and is one-sixth to one-fifth the length of the cyst, carries granules, branched, and distally acuminate. The other processes appear randomly distributed on the test and are slender, solid, tapering, and distally acuminate. No tabulation seen. The archeopyle precingular of the P or 2P type.

Figured material. Loc. 9, 39 (3) at 106·0–35·5.

Dimensions. Range: Length 52·0 (62·0) 84·0 μ; breadth 43·0 (50·3) 63·0 μ, processes vary in length from 2 to 8 μ. Six specimens observed.

Remarks. Except in lacking the pitted nature of the central body and possessing smaller processes, the Bearpaw specimens compare favourably with those of Davey *et al.* (1966). This species had a previously recorded range of Albian–Cenomanian and has possibly gonyaulacacean affinities in the apteodinioid lineage.

Exochosphaeridium pseudohystrichodinium (Deflandre) emend. Davey 1969*a*

Plate 86, fig. 4

1937 *Hystrichosphaeridium pseudohystrichodinium* Deflandre; 73, pl. 15, figs. 3, 4.
1969*a* *Exochosphaeridium pseudohystrichodinium* (Deflandre) emend. Davey; 163, 164, pl. 11, figs. 4, 5.

These specimens compare well with those of Davey (1969*a*) except for the detail of the pitted test. All specimens attributed to this species were granulate. The possession of a slight cingulum in some suggests that this species should be transferred to *Trichodinium* Eisenack and Cookson 1960 but as this is the exception rather than the rule it is assigned as above. It may, however, prove necessary in the future to treat *Exochosphaeridium* as a junior synonym of *Trichodinium*. This species has a geological range of Cenomanian–Eocene, and has possibly gonyaulacacean affinities with the apteodinioid lineage.

Figured material. Loc. 11, 5 (2) at 110·0–31·7.

Dimensions. Range: Length 53·0 (60·1) 71·0 μ; breadth 44·0 (53·3) 69·0 μ, processes range in length from 10 to 20 μ. Six specimens observed.

Exochosphaeridium sp. A

Plate 86, fig. 9

Description. Chorate cyst, subspheroidal in shape, made up of periphragm and endophragm closely adpressed; the former making up the processes. Test smooth. The apical process large, up to one-fifth of the cyst length and branched. The processes solid to membranous, cylindrical, erect to curved and distally oblate to bifurcate. In plan the membranous processes give a reticulate pattern to the cyst surface. Tabulation not observed nor the archeopyle.

Figured material. Loc. 5, 2 (1) at 101·0–33·6.

Dimensions. Range: Length 50·0 (62·8) 98·0 μ; breadth 43·0 (49·8) 60·0 μ, processes range in length from 5 to 10 μ. Five specimens observed.

Remarks. These specimens are unlike all other previously described species of *Exochosphaeridium* but the scarcity of specimens precludes the erection of a new species. The distinguishing feature is the apparent reticulate pattern on the cyst surface. It has possibly gonyaulacacean affinities with the apteodinioid lineage.

Cyst-Family AREOLIGERACEAE Evitt emend. Sarjeant and Downie 1966
Genus CYCLONEPHELIUM Deflandre and Cookson emend. Cookson and Eisenack 1962

Type species. Cyclonephelium compactum Deflandre and Cookson 1955; O.D.

The original diagnosis of this genus was emended by Cookson and Eisenack (1962) and later by Williams and Downie (1966) to correct the interpretation of cyst orientation and to describe fully the range of process structure. The later emendation of Williams and Downie (1966) is nearly word for word the same as that of Cookson and Eisenack (1962).

Cyclonephelium distinctum Deflandre and Cookson 1955

Plate 87, figs. 1, 4

1955 *Cyclonephelium distinctum* Deflandre and Cookson; 285, 286, pl. 2, fig. 14, text-figs. 47, 48.

This species is recorded for the first time from Campanian rocks. Its previously recorded range being Hauterivian–Santonian. A large degree of process variation is observed for this species. *C. distinctum* is characterized by the isolated nature of the process. *C. compactum* Deflandre and Cookson 1955 is very similar except the processes are lamella-like. *C. distinctum* has gonyaulacacean affinities with the areoligeroid lineage.

Figured material. Loc. 13, 5 (1) at 97·0–43·3. Loc. 10, 3 (1) at 108·0–34·6.

Dimensions. Range: Length 37·0 (48·9) 84·0 μ; breadth 39·0 (51·9) 87·0 μ, processes range in length from 2 to 18 μ. Thirty-eight specimens observed.

Cyst-Family SPINIFERITACEAE Sarjeant 1970
Genus SPINIFERITES Mantell *ex* Loeblich and Loeblich 1966

Type species. Spiniferites ramosus (Ehrenberg) Mantell 1854; S.D.

Spiniferites ramosus var. *ramosus* (Davey and Williams) Sarjeant 1970

Plate 87, fig. 7

1966*a* *Hystrichosphaera ramosa* var. *ramosa* Davey and Williams; 33, 34, pl. 1, figs. 1, 6, pl. 3, fig. 1, text-fig. 8.

This variety has a known geological range of Middle Barremian–Ypresian. It has gonyaulacacean affinities with the gonyaulacoid lineage.

Figured material. Loc. 9, 39 (1) at 99·0–38·2.

Dimensions. Range: Length 33·0 (39·2) 46·0 μ; breadth 22·0 (30·3) 35·0 μ, processes range in length from 6 to 18 μ. Thirteen specimens observed.

Spiniferites ramosus var. *multibrevis* (Davey and Williams) Sarjeant 1970

Plate 87, fig. 3

1966*a* *Hystrichosphaera ramosa* var. *multibrevis* Davey and Williams; 35–37, pl. 1, fig. 4, pl. 4, fig. 6, text-fig. 9.

This variety compares well with those figured by Davey and Williams (1966*a*). It is characterized by its short gonal and sutural processes; it has a geological range from Hauterivian–Eocene. Its affinities are gonyaulacacean with the gonyaulacoid lineage.

Figured specimen. Loc. 11, 1 (1) at 103·0–32·4.

Dimensions. Range: Length 20·0 (33·9) 42·0 μ; breadth 18·0 (26·75) 35·0 μ, processes range in length from 3 to 12 μ. Twenty specimens observed.

Spiniferites ramosus var. *granosus* (Davey and Williams) Sarjeant 1970

Plate 87, fig. 8

1966*a* *Hystrichosphaera ramosa* var. *granosa* Davey and Williams; 35, pl. 4, fig. 9.

These specimens compare well with those of Davey and Williams (1966*a*) except in differences of process morphology probably due to specific variability. This variety had previously been recorded only from the Eocene. Its affinities are gonyaulacacean with the gonyaulacoid lineage.

Figured material. Loc. 3, 3 (3) at 96·8–53·5.

Dimensions. Range: Length 39·0 (43·25) 46·0 μ; breadth 32·0 (34·5) 38·0 μ, processes range in length from 9 to 19 μ. Five specimens observed.

Spiniferites cf. *porosus* (Manum and Cookson) comb. nov.

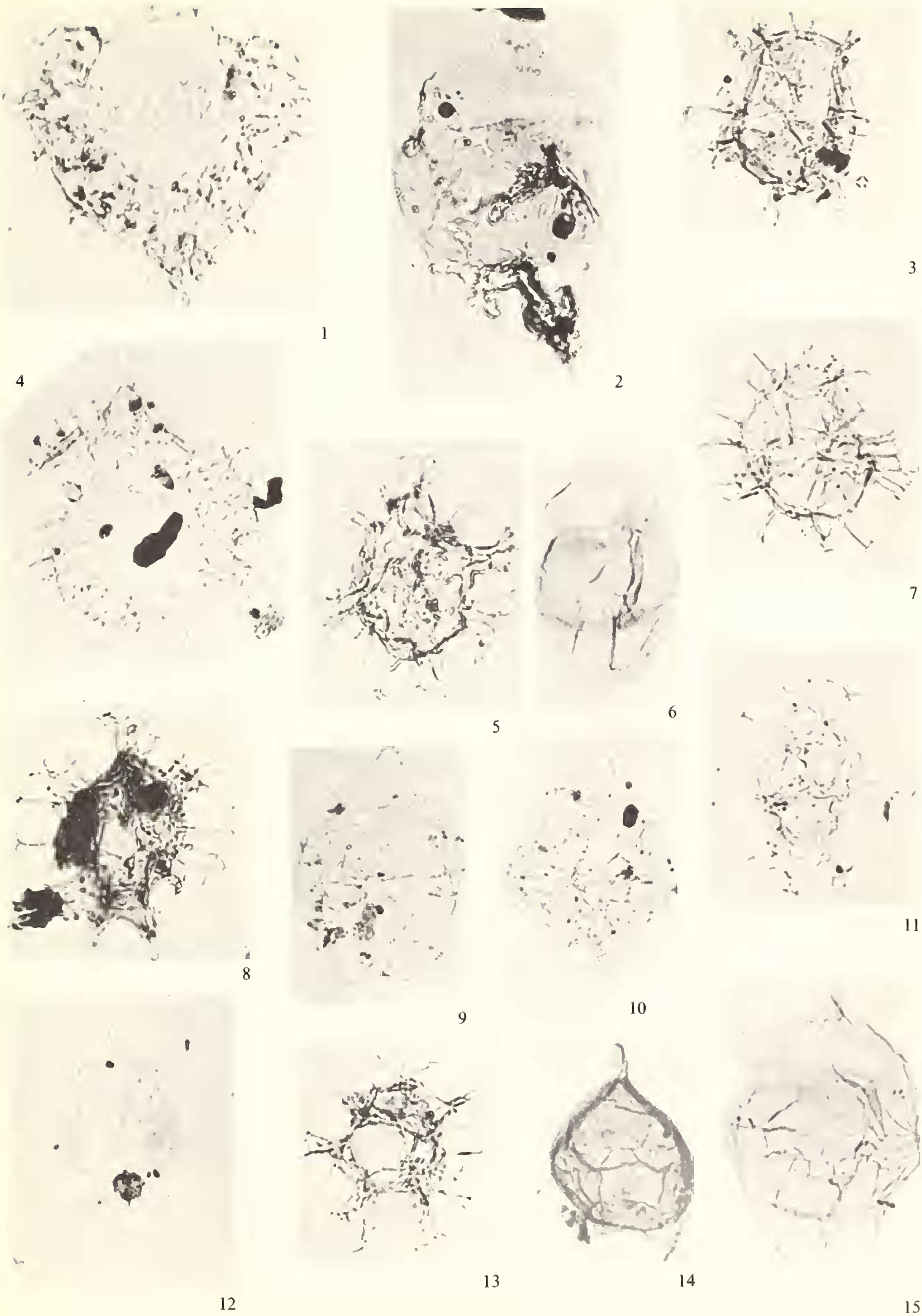
Plate 87, fig. 5

1964 *Hystrichosphaera porosa* Manum and Cookson; 11, 12, pl. 2, figs. 1–5, text-fig. 2.

EXPLANATION OF PLATE 87

All figures at a magnification of ×600 unless otherwise stated.

Fig. 1. *Cyclonephelium distinctum* Deflandre and Cookson, lateral view. Fig. 2. *Deflandrea tripartita* Cookson and Eisenack emend, Cookson and Manum, dorsal view. Fig. 3. *Spiniferites ramosus* var. *multibrevis* (Davey and Williams), lateral view. Fig. 4. *Cyclonephelium distinctum* Deflandre and Cookson, lateral view, showing the operculum. Fig. 5. *Spiniferites* cf. *porosus* (Manum and Cookson), lateral view. Fig. 6. *Deflandrea korojonensis* Cookson and Eisenack, dorsal view. Fig. 7. *Spiniferites ramosus* var. *ramosus* (Davey and Williams), lateral view. Fig. 8. *Spiniferites ramosus* var. *granosus* (Davey and Williams), lateral view. Fig. 9. *Deflandrea spectabilis* Alberti, lateral view of specimen with a conical epitract. Fig. 10. *Deflandrea echinoidea* Cookson and Eisenack, ventral view. Fig. 11. *Spiniferites ramosus* var. *membranaceus* (Rossignol), lateral view. Fig. 12. *Achomosphaera* cf. *hyperacantha* (Deflandre and Cookson) Davey *et al.*, lateral view. Fig. 13. *Spiniferites ramosus* var. *gracilis* (Davey and Williams), lateral view. Fig. 14. *Deflandrea macrocysta* Cookson and Eisenack, lateral view. Fig. 15. *Deflandrea spectabilis* Alberti, dorsal view of specimen with a bell-shaped epitract.



HARLAND, Campanian microfossils

Description. Proximo-chorate cyst, spheroidal to ovoidal in shape, made up of periphragm and endophragm closely adpressed. The endophragm may be thickened; the periphragm makes up the processes. Cyst smooth. Tabulation present with the fields delimited by sutural ridges; no specimen, however, seen in which the tabulation could be deciphered. Processes hollow, latispinous, erect, buccinate, open distally, fenestrate, and digitate. One or two specimens observed in which the cylindrical sutural processes were present. Archeopyle precingular of type P, formed by the loss of plate 3″.

Figured material. Loc. 3, 10 (2) at 109·4–44·8.

Dimensions. Range: Length 33·0 (38·8) 46·0 μ; breadth 22·0 (32·5) 40·0 μ, processes range in length from 8 to 18 μ. Seventeen specimens observed.

Remarks. This species is morphologically similar to *H. porosa* Manum and Cookson 1964 but in certain specimens a similarity with *H. perforata* Davey and Williams 1966 was apparent. It may be that there is a complete morphological range between these two species. *H. porosa* had a recorded geological range of Aptian–Turonian. Its affinities are gonyaulacacean with the gonyaulacoid lineage.

Spiniferites ramosus var. *gracilis* (Davey and Williams) Sarjeant 1970

Plate 87, fig. 13

1966*a* *Hystrichosphaera ramosa* var. *gracilis* Davey and Williams; 34, 35, pl. 1, fig. 5, pl. 5, fig. 6.

These specimens compare well with those of Davey and Williams (1966*a*) except that in the Bearpaw assemblages there is more variability in process length; this may be an indication of a morphological trend from the *ramosus* type to the *gracilis* type. The geological range of this variety is Cenomanian–Miocene. Its affinities are gonyaulacacean with the gonyaulacoid lineage.

Figured material. Loc. 3, 3 (1) at 94·0–47·3.

Dimensions. Range: Length 28·0 (34·5) 49·0 μ; breadth 21·0 (30·5) 38·0 μ, processes range in length from 7 to 18 μ. Thirteen specimens observed.

Spiniferites cf. *membranaceus* (Rossignol) Sarjeant 1970

Plate 87, fig. 11

1964 *Hystrichosphaera furcata* var. *membranacea* Rossignol; 86, pl. 1, figs. 4, 9, 10, pl. 3, figs. 7, 12.
1966*a* *Hystrichosphaera ramosa* var. *membranacea* (Rossignol) Davy and Williams; 37, pl. 4, figs. 8, 12.
1967 *Hystrichosphaera membranacea* (Rossignol) Wall; 102, 103, pl. 14, figs. 14, 15, text-fig. 2.
1970 *Spiniferites membranaceus* (Rossignol) Sarjeant; 76.

These specimens compare well with those of Davey and Williams (1966*a*) but differ from those of Rossignol (1964) in lacking the two large dorsal antapical processes. *S. ramosus* var. *membranaceus* had a previously recorded geological range of Eocene–Recent, and its affinities are gonyaulacacean with the gonyaulacoid lineage.

Figured material. Loc. 11, 1 (1) at 96·0–29·3.

Dimensions. Range: Length 30·0 (35·6) 40·0 μ; breadth 22·0 (27·8) 38·0 μ, processes range in length from 8 to 18 μ. Ten specimens observed.

Genus ACHOMOSPHAERA Evitt 1963

Type species. Achomosphaera ramulifera (Deflandre) Evitt 1963; O.D.

Achomosphaera cf. *hyperacantha* (Deflandre & Cookson) Davey and Williams 1969

Plate 87, fig. 12

1955 *Hystrichosphaera hyperacantha* Deflandre and Cookson; 264, 265, pl. 6, fig. 7.
1967 *Hystrichosphaera hyperacantha* (Deflandre and Cookson) Wall; 100, pl. 14, fig. 3.
1969 *Achomosphaera hyperacantha* (Deflandre and Cookson) Davey and Williams; 4.

Description. Proximo-chorate cyst, spheroidal to ovoidal, consisting of two closely adpressed wall layers. Cyst surfaces smooth. Periphragm alone makes up the hollow processes, which do not connect to the interior of the cyst. They are slender and taeniate, erect, cylindrical to tapering; generally trifurcate with bifid tips. The processes are, like the test, smooth. Sutural ridges absent in general although one or two faint lines may be seen in some specimens. Archeopyle not observed.

Figured material. Loc. 13, 13 (2) at 94·0–32·6.

Dimensions. Range: Length 37·0 (38·0) 39·0 μ; breadth 32·0 (32·5) 33·0 μ, length of processes 6 to 15 μ. Two specimens observed.

Remarks. This species has recently been formally transferred to the genus *Achomosphaera* by Davey *et al.* (1969). The observed specimens were smaller than the original specimens of Deflandre and Cookson (1955). Wall (1967) considers this species as being a robust variety of *H. furcata* (Ehrenberg) Wetzel. It is, however, probably best regarded as a morphotype within the '*Spiniferites* complex'. *Achomosphaera hyperacantha* has a recorded geological range of Lower Miocene?–Holocene. The geological range should only be extended with some reserve on the evidence of only two specimens. It is characterized, in particular, by the nature of its trifurcate processes. It is almost certainly a gonyaulacacean dinoflagellate of the gonyaulacoid lineage.

Cyst-Family DEFLANDREACEAE Eisenack emend. Sarjeant and Downie 1966
Genus DEFLANDREA Eisenack emend. Williams and Downie 1966

Type species. Deflandrea phosphoritica Eisenack 1938; O.D.

Williams and Downie (1966) state that this genus is represented by many species that clearly overlap with regard to their morphology. It is probably best to regard this genus as embracing a complex of morphotypes that show geographical and evolutionary intergradation; but at any one level in the stratigraphic column, a number of morphotypes may be recognized. The species described below are regarded in this light. Vozzhennikova (1967) created two new genera, *Chatangiella* and *Australiella*, and emended the genus *Deflandrea* in her treatment of *Deflandrea*-like cysts. The present author is reluctant to follow this scheme at the present time.

Deflandrea spectabilis Alberti 1959

Plate 87, figs. 9, 15

1959 *Deflandrea spectabilis* Alberti; 99, pl. 9, figs. 7, 8.

This species is common in the Bearpaw Formation, it has a large specific variation as interpreted from the assemblages studied, and it is not difficult to visualize that with more of a conical epitract it would appear very similar to *D. cooksoni* as figured by Clarke and Verdier (1967); but with a bell-shaped epitract it is closer to the holotype of *D. cooksoni* Alberti (1959). Vozzhennikova (1967) regards this species as a member of the genus *Australiella. D. spectabilis* has a geological range of Santonian–Campanian. Manum (1963) reported a peridiniacean tabulation for certain species of *Deflandrea*, and Wall and Dale (1968) place it in the deflandreoid lineage.

Figured material. Loc. 5, 1 (3) at 103·0–44·3. Loc. 11, 1 (1) at 95·0–35·9.

Dimensions. Range: Length 58·0 (65·5) 87·0 μ; breadth 32·0 (41·7) 50·0 μ. Fifty specimens measured, out of a studied population of seventy-four.

Deflandrea korojonensis Cookson and Eisenack 1958

Plate 87, fig. 6

1958 *Deflandrea korojonensis* Cookson and Eisenack; 27, pl. 4, figs. 10, 11.

This species may be distinguished from *D. spectabilis* by its over-all shape and the absence of any type of tabulation. It forms a distinct morphotype within these assemblages. It is, however, close to *D. bakeri*, Deflandre and Cookson 1955, the major difference being the nature of 'ornamentation', *D. bakeri* having a punctate test. Vozzhennikova (1967) regards this species as a member of the genus *Australiella. D. korojonensis* has a geological range of Campanian–Maestrichtian. It has peridiniacean affinities with the deflandreoid lineage.

Figured material. Loc. 13, 5 (1) at 93·0–44·2.

Dimensions. Range: Length 70·0 (97·4) 132·0 μ; breadth 40·0 (56·6) 82·0 μ. Thirteen specimens observed and measured.

Deflandrea echinoidea Cookson and Eisenack 1960

Plate 87, fig. 10

1960 *Deflandrea echinoidea* Cookson and Eisenack; 2, pl. 1, figs. 5, 6.

This species forms a distinct morphotype within the Bearpaw Formation by virtue of its 'ornamentation', but it is otherwise morphologically similar to *D. spectabilis. D. echinoidea* has a geological range of Albian–Campanian. It has peridiniacean affinities with the deflandreoid lineage.

Figured material. Loc. 11, 7 (2) at 102·0–47·7.

Dimensions. Range: Length 60·0 (67·0) 71·0 μ; breadth 45·0 (48·3) 50·0 μ. Two specimens observed.

Deflandrea tripartita Cookson and Eisenack emend. Cookson and Manum 1964

Plate 87, fig. 2

1960 *Deflandrea tripartita* Cookson and Eisenack; 2, pl. 1, fig. 10.

This species is similar to *D. victoriensis* but differs in that it lacks all traces of tabulation. Vozzhennikova (1967) regards this species as a member of the genus

Australiella. D. tripartita has a geological range of Turonian–Campanian. It has peridiniacean affinities with the deflandreoid lineage.

Figured material. Loc. 4, 13 (2) at 107·8–30·9.

Dimensions. Range: Length 75·0 (94·0) 105·0 μ; breadth 35·0 (48·6) 62·0 μ. Six specimens observed and measured.

Deflandrea macrocysta Cookson and Eisenack 1960

Plate 87, fig. 14

1960 *Deflandrea macrocysta* Cookson and Eisenack; 3, pl. 1, figs. 7, 8.

This species forms a distinct morphological type in Bearpaw assemblages. In general it appears quite close to *Trithyrodinium evittii* Drugg 1967 but differs in possessing an intercalary archeopyle formed by the loss of a single plate. It has peridiniacean affinities with the deflandreoid lineage.

Figured material. Loc. 1, 13 (2) at 99·2–39·0.

Dimensions. Range: Length 44·0 (67·6) 78·0 μ; breadth 36·0 (47·6) 54·0 μ. Ten specimens observed and measured.

Cyst-Family PSEUDOCERATIACEAE Eisenack emend. Sarjeant and Downie 1966
Genus ODONTOCHITINA Deflandre 1935

Type species. Odontochitina operculata (Wetzel) Deflandre 1946 = *Odontochitina silicorum* Deflandre 1935; O.D.

Odontochitina operculata (Wetzel) Deflandre 1946

Plate 88, fig. 1

1933 *Ceratium* (*Euceratium*) *operculatum* Wetzel; 170, pl. 2, figs. 21, 22.
1946 *Odontochitina operculata* (Wetzel) Deflandre; 238, figs. 1016–19.

This was the only species of *Odontochitina* observed in the Bearpaw assemblages. It is distinguished from *O. costata* Alberti emend. Clarke and Verdier 1967, which in many respects it closely resembles, by lack of striations on the horns. It is uncertain whether the horns of *Odontochitina* are equivalent to horns as seen in many modern species of *Ceratium* or whether they should be more correctly termed processes. Its affinities are unknown.

Figured material. Loc. 9, 39 (2) at 99·0–32·9.

Dimensions. Range: Endoblast: length of long axis 42·0 (53·9) 71·0 μ, length of short axis 39·0 (49·9) 68·0 μ. The horns range in length from 54·0–200·0 μ. Thirty-one specimens observed.

In addition to these species the following were noted, but were only represented by single specimens. They are, therefore, not herein described or figured but are included in the primary data and in the range charts.

Cribroperidinium sp.
Pareodinia sp.

Komewuia cf. *glabra* Cookson and Eisenack 1960
Canningia cf. *rotundata* Cookson and Eisenack 1961
Exochosphaeridium bifidum (Clarke and Verdier) Clarke *et al.* 1968
Cyclonephelium cf. *paucispinum* Davey 1969
Spiniferites cornutus (Gerlach) var. A
Deflandrea granulifera Manum 1963
D. sp.
Hexagonifera chlamydata Cookson and Eisenack 1962*b*

INCERTAE SEDIS
Group ACRITARCHA Evitt 1963
Subgroup ACANTHOMORPHITAE Downie, Evitt, and Sarjeant 1963
Genus BALTISPHAERIDIUM Eisenack emend. Downie and Sarjeant 1963

Baltisphaeridium sp. A. (Pl. 88, fig. 5.) Loc. 11, 9 (1) at 105·0–38·0. Thirty-one specimens.

Genus *Micrhystridium* Deflandre emend. Downie and Sarjeant 1963

Micrhystridium sp. A. (Pl. 88, figs. 2, 3.) Loc. 2, 1 (1) at 93·0–45·4 and Loc. 3, 13 (2) at 108·0–35·6. Twenty-three specimens.
Micrhystridium sp. B. (Pl. 88, fig. 7.) Loc. 3, 13 (2) at 109·0–39·4. Twenty-seven specimens.
Micrhystridium sp. C. (Pl. 88, fig. 4.) Loc. 3, 10 (3) at 93·5–38·1. Seven specimens.
Micrhystridium sp. D. (Pl. 88, fig. 6.) Loc. 3, 10 (2) at 94·6–43·2. Nine specimens.

Subgroup HERKOMORPHITAE Downie, Evitt and Sarjeant 1963
Genus CYMATIOSPHAERA Wetzel emend. Deflandre 1954

Cymatiosphaera sp. A. (Pl. 88, fig. 8.) Loc. 3, 1 (1) at 106·0–47·1. Ten specimens.

INTERPRETATION OF THE BEARPAW PHYTOPLANKTONIC RECORD

The Bearpaw assemblage. The Bearpaw Formation contains a distinct assemblage of dinoflagellate cysts and acritarchs. In particular it is characterized by the presence of the genera *Deflandrea*, *Diconodinium*, and *Lejeunia*. To characterize the assemblage further it is necessary, though difficult, to give some idea of the relative proportions of certain of the cysts present. In a qualitative sense, therefore, the following three categories are used: 'common', 'occasionally common', and 'rare'.

EXPLANATION OF PLATE 88

All figures at a magnification of ×600 unless otherwise stated.

Fig. 1. *Odontochitina operculata* (Wetzel) Deflandre, lateral view, showing the archeopyle and the nature of the horns. Fig. 2. *Micrhystridium* sp. A, general view to show the cyst habit. Fig. 3. *Micrhystridium* sp. A, general view, showing the nature of the processes. Fig. 4. *Micrhystridium* sp. C, general view, showing the nature of the processes. Fig. 5. *Baltisphaeridium* sp. A, general view, showing the cyst habit. Fig. 6. *Micrhystridium* sp. D, general view, showing the nature of the processes. Fig. 7. *Micrhystridium* sp. B, general view, showing the cyst habit. Fig. 8. *Cymatiosphaera* sp. A, general view, showing the polygonal fields on the central body and the nature of the processes.

HARLAND, Campanian microfossils

The Bearpaw assemblages studied always had high proportions of the following cysts: *Deflandrea spectabilis* Alberti, *Diconodinium firmum* sp. nov., and *Oligosphaeridium pulcherrimum* (Deflandre and Cookson) Davey and Williams. These species are regarded as being 'common'. Some of the assemblages, in addition to those mentioned above, contain high proportions of *Canningia senonica* Clarke and Verdier, *Microdinium irregulare* Clarke and Verdier, *Lejeunia ampla* sp. nov., *L. tricuspis* (Wetzel), *Odontochitina operculata* (Wetzel) Deflandre, *Cyclonephelium distinctum* Deflandre and Cookson, *Hystrichosphaeridium tubiferum* var. *brevispinum* Davey and Williams and *Deflandrea korojonensis* Cookson and Eisenack. These species are regarded as 'occasionally common'. All other species recovered from the Bearpaw Formation are 'rare'.

Comparisons with other assemblages are difficult to make as little work has been published with respect to Campanian microplankton. Cookson and Eisenack (1960) described some types from Western Australia with some similar *Deflandrea* species to those from the Bearpaw Formation. In addition they recorded a unique collection of species. Clarke and Verdier (1967) recorded very few species of dinoflagellate cysts and acritarchs from the Campanian of the Isle of Wight. Species common to their assemblage and the present assemblage are *Exochosphaeridium bifidum* (Clarke and Verdier) Clarke *et al.* 1968, *Cyclonephelium distinctum*, and *Odontochitina operculata*. Vozzhennikova (1967), in her tables of diagnostic species, lists the following for the Campanian of Kazakhstan: *Gymnodinium kasachstanium* Vozzhennikova, *Australiella cooksoni* (Alberti) Vozzhennikova, *A. granulifera* (Manum) Vozzhennikova, *Albertia curvicornis* Vozzhennikova and *Cooksoniella manumi* Vozzhennikova. Similarities exist to the Bearpaw assemblages especially with regard to the *Deflandrea* species. Oltz (1969) recorded the presence of *Deflandrea* aff. *micrograuulata* Stanley, *Deflandrea* sp., *Hystrichosphaeridium* aff. *tubiferum* (Ehr.) Deflandre, *Hystrichosphaeridium*, cf. *Gonyaulacysta*, Forma 'A', Forma 'B', Forma 'C', and *Paleotetradinium* sp. from the Bearpaw Formation of east central Montana. His assemblage appears similar to that described in this work but a full comparison is not possible as he failed to place his specimens in formal taxa. Recently Davey (1969*b*, 1969*c*) described dinoflagellate cysts from the Campanian of South Africa. His assemblages do not appear comparable except for the presence of *Diconodinium* spp. and *Exochosphaeridium bifidum*.

Local biostratigraphy. The Bearpaw Formation is interpreted as containing a number of informal microplankton assemblage zones. At Lethbridge three informal assemblage zones are recognized from the distribution of the contained microplankton. These have been labelled I to III on fig. 12. The primary data, i.e. number of specimens of each organic-walled microplankton species per assemblage, on which figs. 12 and 13 are based may be obtained from the author on request.

The first assemblage zone encompasses a body of rock contained between 10 feet above the base of the Bearpaw to approximately 160 feet above the base of the formation.

The second informal assemblage zone consists of a body of rock 190 feet above the base of the formation to approximately 260 feet above the base of the formation.

The third assemblage zone consists of a body of rock from 305 feet above the base of the Bearpaw to approximately 540 feet above the base of the formation.

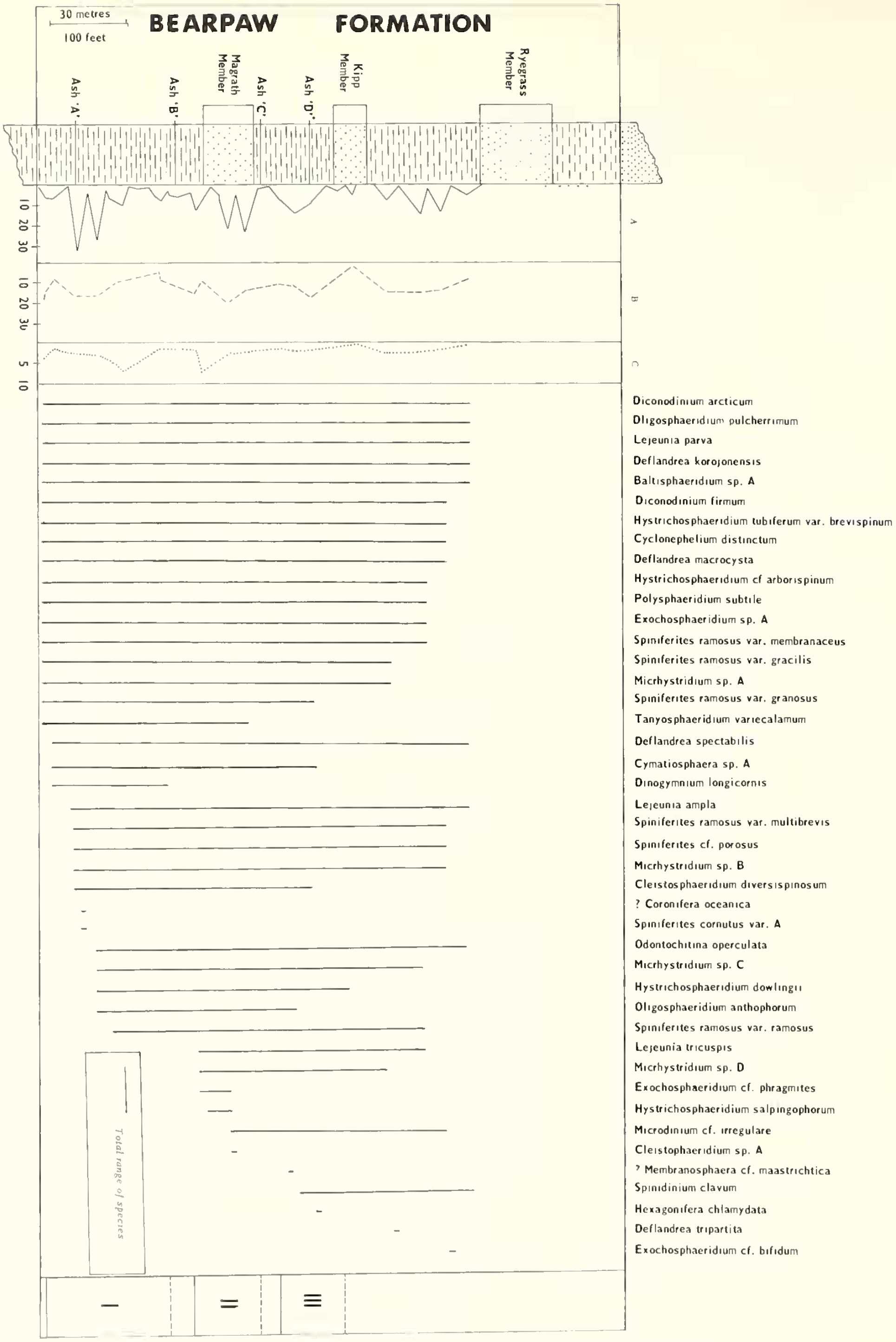
In the Cypress Hills sections only two informal assemblage zones were initially recognized, as part of the Manyberries Member could not be sampled because of poor exposure and lack of stratigraphic control. A lower assemblage zone was recognized (see fig. 13), and an upper assemblage zone was also present although its full limits could not be ascertained.

Recently the author, through the courtesy of Dr. J. H. Wall of the Research Council of Alberta, has examined a part of the core of water borehole RCA Thelma (Lsd 14, Sec. 31, Tp. 6, R. 2, W 4th Mer) to complete that part of the Cypress Hills sections not originally studied. The additional data has been added to all the relevant diagrams and the samples and slides have been deposited in the Palynological Collections at the Institute of Geological Sciences, Leeds, and registered as SAL 1720–SAL 1726. The samples from RCA Thelma confirm the presence of informal assemblage zone II in the Cypress Hills based on the use of the semi-quantitative procedures, i.e. percentages of dinoflagellates and acritarchs, the number of dinoflagellate cyst species and on the gonyaulacacean ratio discussed below, but not on the ranges of the organic-walled microplankton (see fig. 13).

The recognition of the majority of these informal microplankton assemblage zones rests on the vertical distribution of the microplankton in the Bearpaw Formation. A clear correlation by species inspection between these two areas is not possible but both areas do reflect, in the distribution of the dinoflagellate cysts and acritarchs, the transgression and various environmental changes of the Bearpaw sea.

Palaeoenvironment of the Bearpaw. The Lethbridge section of the Bearpaw Formation was examined for its foraminiferan content by Anan-Yorke (1969). He recognized six cycles of water-depth fluctuations and it was suggested that salinity changes accompanied these fluctuations. An attempt has been made to recognize these fluctuations using dinoflagellate cysts and acritarchs.

A record was kept of the percentage of dinoflagellate cysts and acritarchs present in the total palynomorph population in each sample examined. This information is shown in column A of figs. 12 and 13. In addition, in those samples that were studied in detail, i.e. those where the percentage of dinoflagellates and acritarchs rose to 10% or more, a record of the number of dinoflagellate species was kept, and this is shown in column B of the two range charts. Column C records the gonyaulacacean ratio, for each of the samples studied in detail. The gonyaulacacean ratio is simply the number of species that have a gonyaulacacean affinity divided by the number of species having a peridiniacean affinity. If we assume that conditions have not radically altered from today, then it appears that in an open marine environment the number of gonyaulacacean dinoflagellate species is relatively higher than the number of peridiniacean dinoflagellate species (Schiller 1937). We must assume that this is reflected in the cyst populations. In Wall (1967) the calculated gonyaulacacean ratio is 18·0 for cysts collected from deep-sea cores in the Caribbean, and Wall and Dale (1968) has a calculated gonyaulacacean ratio of 0·44 for a near-shore cyst population at Woods Hole, Massachusetts. Freshwater assemblages have high proportions of peridiniacean dinoflagellates and low proportions of gonyaulacacean dinoflagellates



TEXT-FIG. 12. Vertical ranges of the dinoflagellate cysts and acritarchs recovered from the Lethbridge sections of the Bearpaw Formation together with the proposed informal biostratigraphical zonation.

Column A—Percentages of phytoplankton per sample.

Column B—Number of dinoflagellate cyst species per sample.

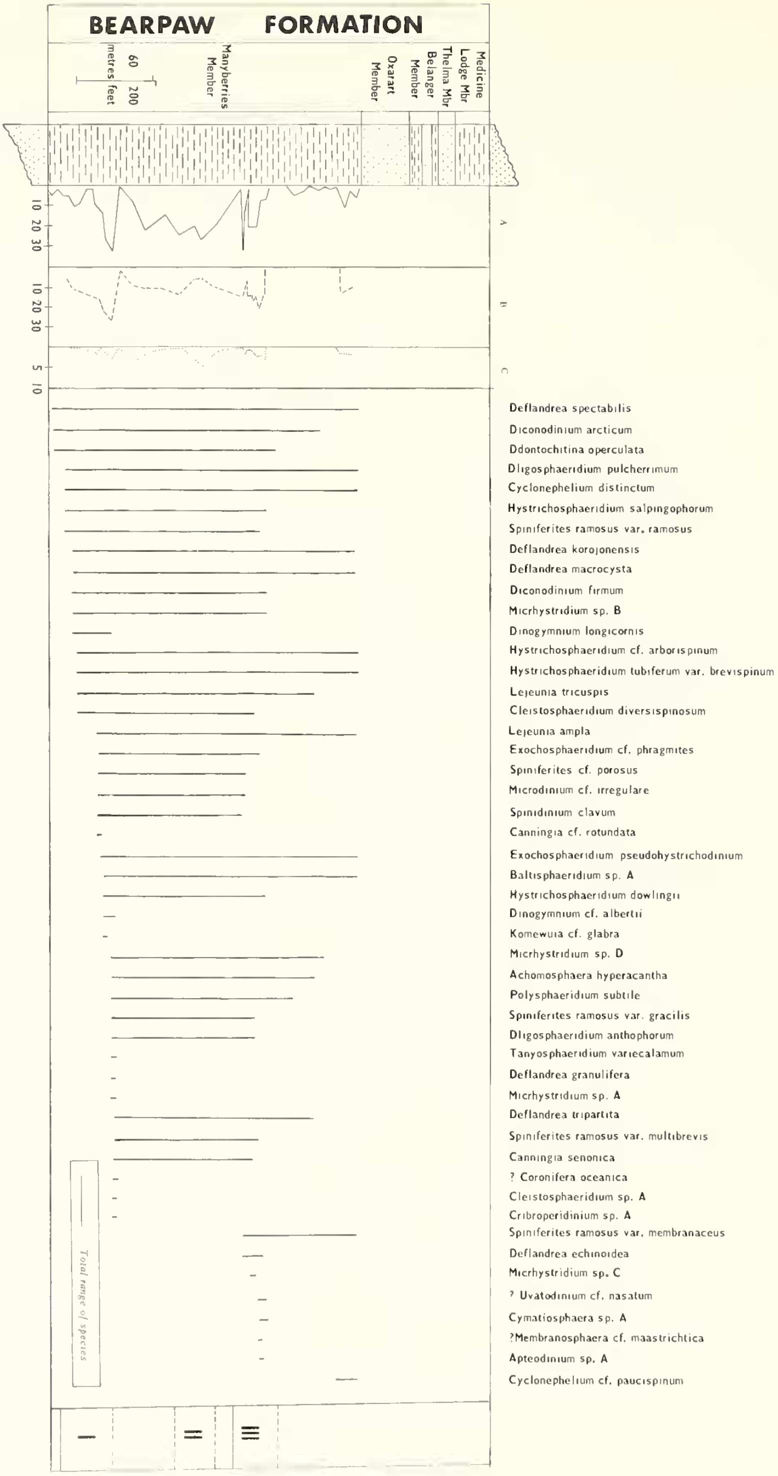
Column C—Gonyaulacacean ratio.

as may be seen in Eddy (1930) and Thompson (1947, 1950). The gonyaulacacean ratio was calculated for each of the samples studied in detail, using cysts for which their natural affinities are known or reasonably assured. The results are shown in column C of the range charts.

An inspection of these three columns (A–C) from the Lethbridge section reveals that an increase in the percentages of the dinoflagellates and acritarchs is accompanied by an increase in the number of species and by an increase in the gonyaulacacean ratio. This relationship may be used to pinpoint the appearance of possible open marine conditions. The author has no justification in setting definite limits on this environment, in terms of salinity, temperature, etc., so the term open marine is used only in a relative sense. These open marine conditions may be indicative of periods of maximum extent of the Bearpaw sea such that the shoreline is distant with the accompanying normal salinity for ocean waters. It might, however, indicate periods when the nutrient content of the sea was optimum for the phytoplankton. Using this information it may be interpreted that an initial flooding or transgression in the Lethbridge area is represented by the lowermost 150 feet of the formation with optimum open marine conditions between 60 and 100 feet above the base of the formation. A second period of open marine conditions is represented from approximately 180–240 feet above the base of the formation and a third period is represented from approximately 310–350 feet above the base of the formation. Many more minor fluctuations are apparent in column A, but on an individual basis these are difficult to explain and may indeed be entirely spurious.

In comparing the results from the dinoflagellate cysts and acritarchs with those from the foraminiferans a close similarity is evident. Anan-Yorke (1969) categorizes his zones as follows: (5) 450 feet to Ryegrass Member—lagoonal. (4) 200–450 feet—deeper water but not as deep as in 2. (3) 115–200 feet—lagoonal, brackish. (2) 56–115 feet—open marine. (1) Basal 56 feet—lagoonal, brackish. Anan-Yorke's zone 2 corresponds quite well with the time of optimum conditions for the initial flooding of the Bearpaw sea as documented by the dinoflagellates and acritarchs. These fossils also pick out a second period of optimum conditions at the level of the Magrath Member which Anan-Yorke unfortunately failed to examine for foraminiferans because of lack of samples. Dinoflagellate and acritarch evidence suggests fluctuating conditions for zone 5 of Anan-Yorke. In the Cypress Hills the period of initial flooding can be recognized together with the other open marine periods. A correlation of the marine palaeoenvironments is thus achieved.

Although the use of the gonyaulacacean ratio appears to be a useful technique it may, in this case, more precisely indicate that the *Deflandrea* spp. prefer a near-shore reduced salinity situation; as the majority of the peridiniacean cysts studied were species of the genus *Deflandrea*. Certain over-all limitations do exist. The palynologist, in studying microplankton, is looking at the cyst and not the motile stage of the life cycle. To what extent does the cyst population reflect the true population of these organisms in their natural habitat? Under what conditions do cysts form and what factors have affected their distributions in the sediments from which they are extracted? These two largely unanswered questions clearly point out the present limitations of all dinoflagellate and acritarch research.



TEXT-FIG. 13. Vertical ranges of the dinoflagellate cysts and acritarchs recovered from the Cypress Hills sections of the Bearpaw Formation together with the possible equivalent informal biostratigraphical units to those proposed for the Lethbridge area. Column explanations the same as those given for text-fig. 12.

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APPENDIX A: SAMPLE LOCALITIES

Sample localities previously mentioned in the text are listed below with their code numbers and geographical locations.

Lethbridge Area. Loc. 1: Lsd. 1, Sec. 2, Tp. 7, R. 22, W.4th Mer.
Loc. 2: Lsd. 9–10, Sec. 33, Tp. 6, R. 22, W.4th Mer.
Loc. 3: Lsd. 15, Sec. 32, Tp. 6, R. 22, W.4th Mer.
Loc. 4: Lsd. 11, Sec. 19, Tp. 6, R. 22, W.4th Mer.
Loc. 5: Lsd. 10–15, Sec. 24, Tp. 6, R. 23, W.4th Mer.
Loc. 6: Lsd. 12, Sec. 34, Tp. 9, R. 23, W.4th Mer.
Loc. 7: Lsd. 1–2, Sec. 32, Tp. 9, R. 23, W.4th Mer.

Cypress Hills Area. Loc. 8: Lsd. 6, Sec. 31, Tp. 11, R. 2, W.4th Mer.
Loc. 9: Lsd. 12, Sec. 14, Tp. 11, R. 3, W.4th Mer.
Loc. 10: Lsd. 6, Sec. 32, Tp. 5, R. 4, W.4th Mer.
Loc. 11: Lsd. 7, Sec. 32, Tp. 5, R. 2, W.4th Mer.
Loc. 12: Lsd. 12, Sec. 5, Tp. 6, R. 2, W.4th Mer.
Loc. 13: Lsd. 5, Sec. 25, Tp. 6, R. 3, W.4th Mer.
Loc. 14: Lsd. 1–2, Sec. 7, Tp. 8, R. 3, W.4th Mer.

REX HARLAND
Institute of Geological Sciences
Ring Road, Halton
Leeds, LS15 8TQ

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